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Environmental Impact Assessment Tenke Fungurume Project

Volume C: Impact Assessment

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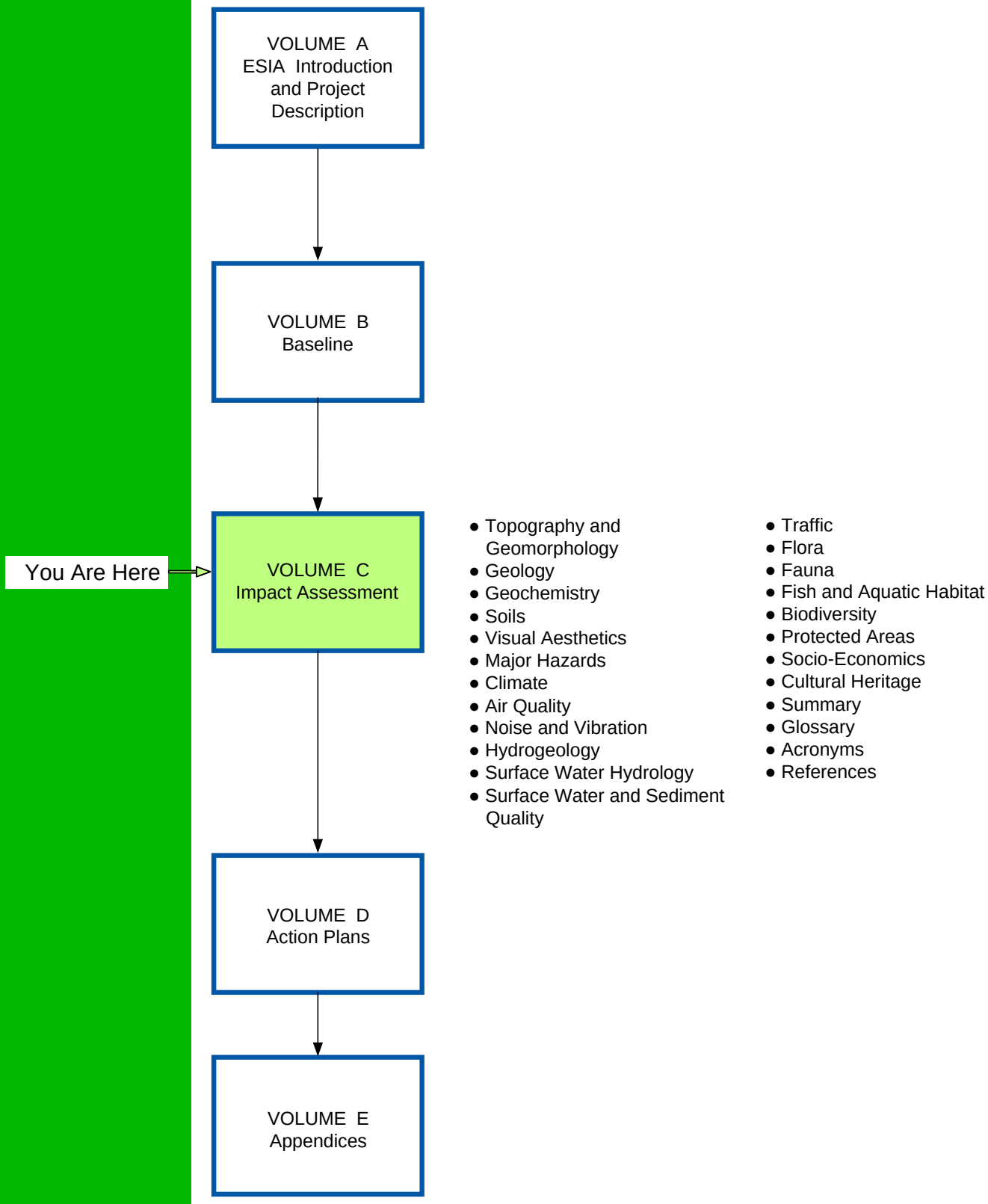
Golder Associates

Tenke Fungurume Project
Tenke Fungurume Mining SARL
Application Road Map



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C1 ESIA STUDY AREAS

Defining the geographic extent of study areas is a key element of an environmental and social impact assessment (ESIA). For the assessment of local impacts, the area should be large enough to efficiently analyze and minimize the obvious potential effects from the project on the receiving environment. The area should also not be too large so as not to dilute or confound the potential project-related effects with other human-induced and natural influences. The assessment of potential broader or regional cumulative effects from the project in association with other human activities and natural factors requires a larger geographic area, and may be based on ecological and/or land use and planning criteria. Such a study area is termed a Regional Study Area (RSA).

Typically, the assessment of impacts within the local area of the project, or the Local Study Area (LSA), is based on the spatial extent of the project's footprint and an associated buffer zone. The buffer zone includes potential immediate indirect effects on the receiving environment. Study areas may also be specific to environmental discipline and individual components of the project such as a particular ore body, plant site or other facility.

Impact assessment study areas for the Tenke Fungurume Mining (TFM) project were selected based upon the expected areas of influence of the project for each of the following environmental and social disciplines:

- Air quality.
- Noise and vibration.
- Visual aesthetics.
- Groundwater.
- Hydrology, water quality and aquatic resources.
- Terrestrial (soils, flora, fauna, natural habitats and biodiversity).
- Protected areas.
- Socio-economics.
- Cultural heritage.

The assessment LSA for each discipline is based on the spatial extent of the footprint, including alternative project elements, and an associated buffer zone that includes potential immediate indirect effects on the receiving environment.

Specifically, the assessment LSAs include the following components associated with the TFM project:

- Mine pits at Kwatebala, Goma and Fwaulu.
- Waste rock facilities.
- Limestone quarry.
- Processing plant site (and alternatives).
- Tailings storage facility (and alternatives).
- Water dam (and alternatives).
- Work camps (and alternatives).
- Roads (and alternatives).
- Airstrip.

However, some discipline (e.g., noise, hydrology, groundwater, water quality) could not conduct an assessment of the Goma and Fwaulu pits due to lack of detailed mine design and/or baseline data. These disciplines therefore assessed the Goma and Fwaulu pits in a qualitative manner as part of the cumulative effects assessment. A full assessment of these pits will be conducted prior to their development.

The assessment RSAs were developed based on the cumulative effects assessment case (Section A5.5.1) and included the area of the following components or their effects:

- Potential mining of ore at Kwatebala, Goma, Fwaulu and Fungurume.
- Potential expansion of the proposed Kwatebala processing plant to a production of 200,000 tonnes per year of copper.
- Potential construction of a second processing plant north of Fungurume with a production of 200,000 tonnes per year of copper.
- Potential construction of an above-ground 250-hectare tailings storage facility north of Fungurume.
- Potential disposal of waste rock near Goma, Kwatebala and Fungurume pits.
- Potential expansion of the construction camp and additional facilities as required.

In general, RSAs were purposefully kept large due to the lack of definition of many of the above components.

Baseline study areas are presented in Section B1.

C1.1 AIR QUALITY

Anticipated emissions from the processing plant could have a downwind impact of up to 10 kilometers, so air quality study areas were based on this distance. The air quality assessment RSA was selected to investigate the cumulative effects of the TFM project with potential future expansions, including construction and operation of a second processing plant north of Fungurume and mining at Fungurume. The RSA thus encompasses two 20 by 20 kilometer square areas, with one centered on the proposed Kwatebala processing plant and one centered on the Fungurume processing plant (Figure C1.1-1) (The two squares overlap, thus the left edge of the square centered on the Fungurume plant site is indicated by a dashed line). The air quality assessment LSA was selected to be a single 20 by 20 kilometer square area centered on the proposed Kwatebala processing plant (Figure C1.1-1). The LSA allows for the assessment of the effects of the mine facilities on local air quality.

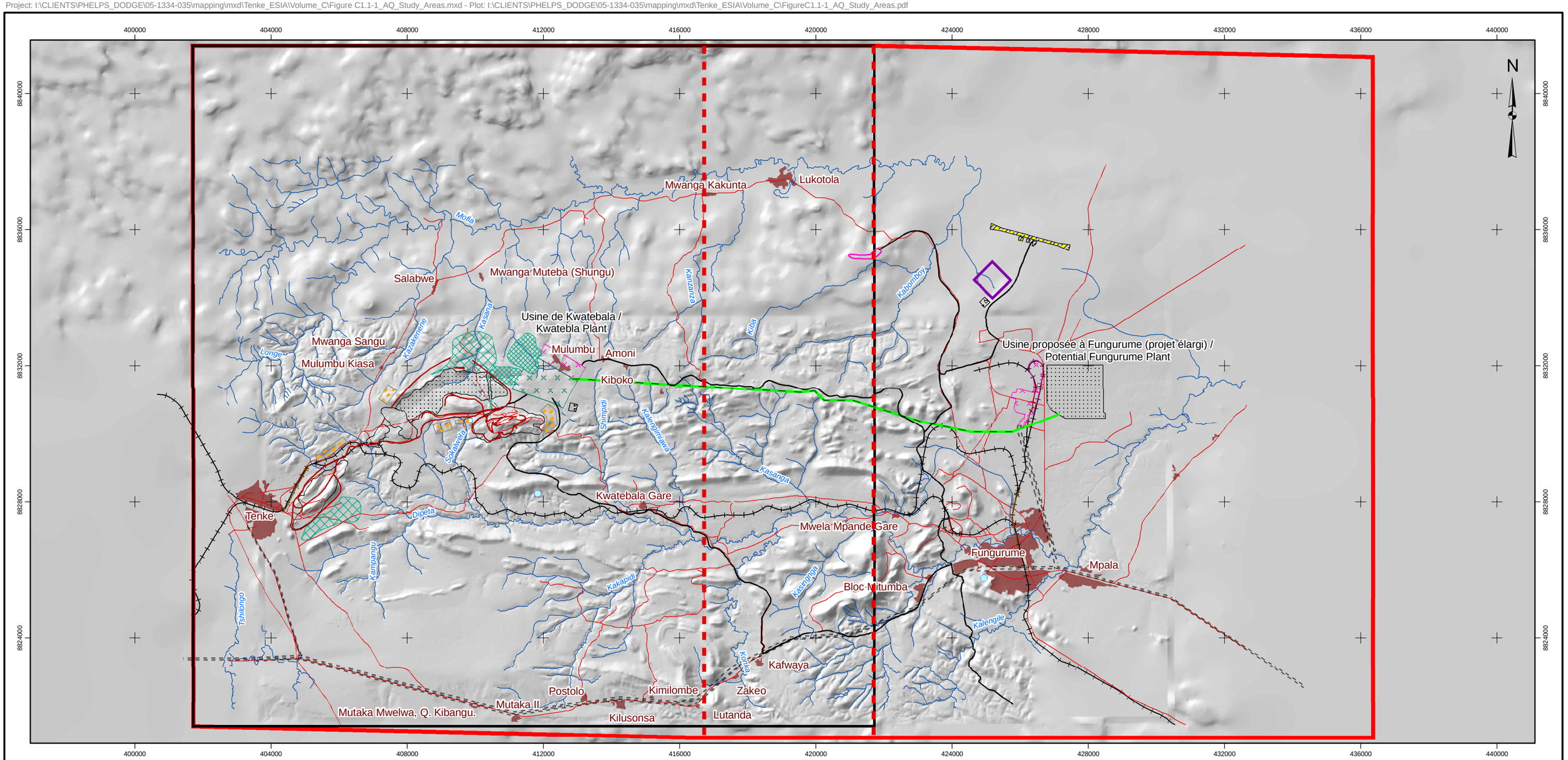
C1.2 NOISE AND VIBRATION

The noise and vibration assessment RSA for the project was selected based on:

- Extent of TFM project activities.
- Expected sound level and vibration emissions.
- Locations of sensitive receptors.

The RSA for noise and vibration is a 16 by 30 kilometer rectangle surrounding the ore bodies between Tenke and Fungurume (Figure C1.2-1).

The assessment LSA for noise and vibrations extends two kilometers from the limits of project activity except for material transport routes, such as roads and the airstrip. The LSA extends 500 meters from these routes on both sides (Figure C1.2-1). Study area limits for a North American traffic noise assessment are typically 200 meters from a public road. A 500-meter buffer for the material transport route was conservatively designed to include all potentially affected noise and vibration receptors along the routes. Specific villages and towns within the LSA were also assessed. Neighboring villages and towns are all potential noise or vibration-sensitive receptors located within the LSA boundary.



LÉGENDE / LEGEND

- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- ZONE D'ÉTUDE LOCALE - QUALITÉ DE L'AIR / LOCAL STUDY AREA - AIR QUALITY
- ZONE D'ÉTUDE RÉGIONALE - QUALITÉ DE L'AIR / REGIONAL STUDY AREA - AIR QUALITY

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE L'IMPLANTATION FUTURE / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE 1:110000 KILOMÈTRES
SCALE 1:110000 KILOMETERS

PROJET / PROJECT

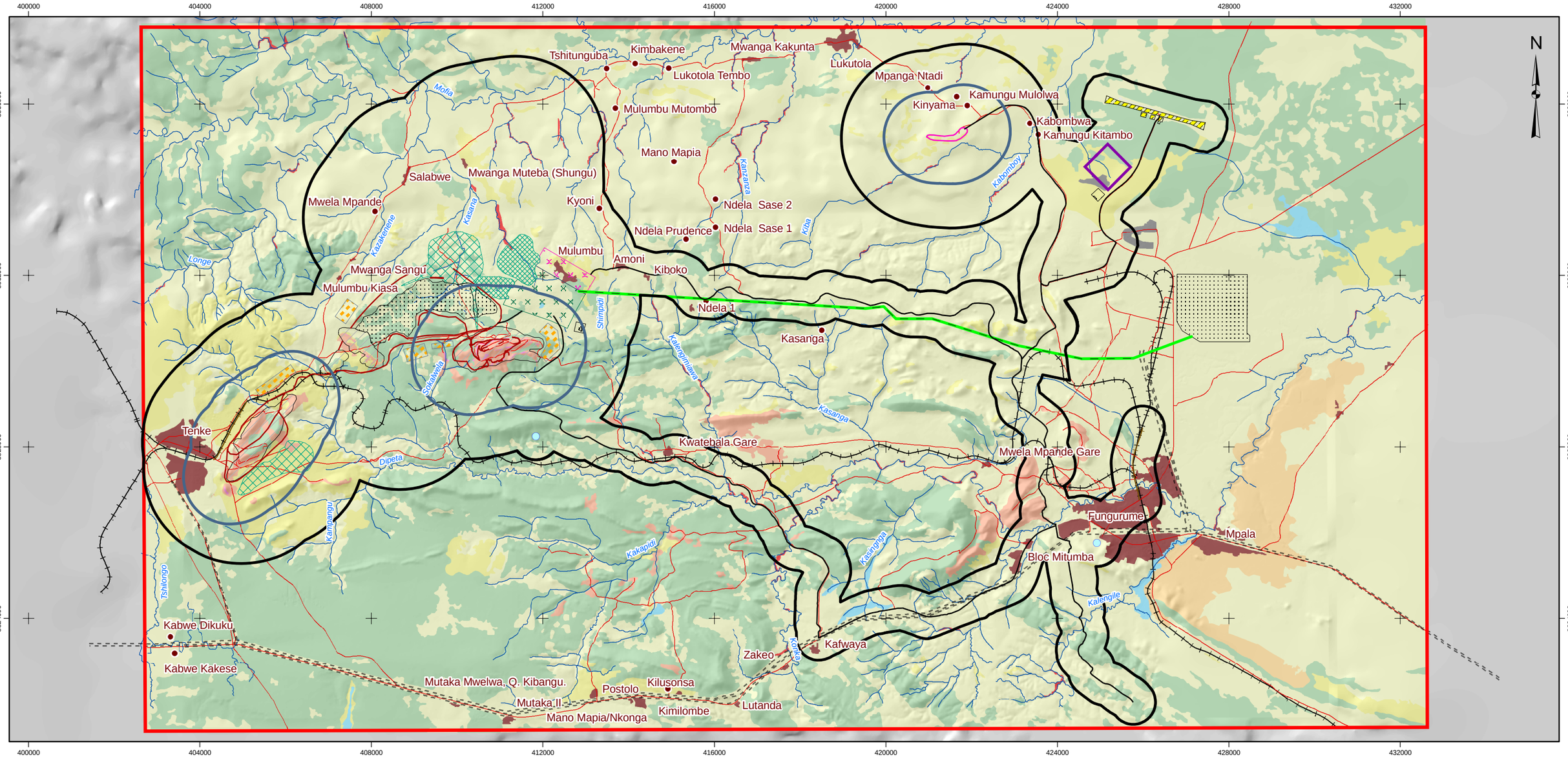
PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE **ZONE D'ÉTUDE POUR L'ÉVALUATION DE LA QUALITÉ DE L'AIR / AIR QUALITY ASSESSMENT STUDY AREAS**

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	GJ	22 Jun. 2006		
GIS / SIG	TN	03 Jan. 2007		
VÉRIFIÉ / CHECK	MR	20 Oct. 2006		
APPROUVÉ REVIEW	MR	20 Oct. 2006		

FIGURE: C1.1-1



LÉGENDE / LEGEND

- VILLAGE
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- ZONE D'ÉTUDE LOCALE - BRUIT / LOCAL STUDY AREA - NOISE
- ZONE D'ÉTUDE LOCALE - VIBRATION / LOCAL STUDY AREA - VIBRATION
- ZONE D'ÉTUDE RÉGIONALE / REGIONAL STUDY AREA

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE L'IMPLANTATION FUTURE / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

COUVERTURE VÉGÉTALE / UTILISATION DU TERRAIN / LANDCOVER

- AFFLEUREMENT ROCHEUX DE MINERAI CUIVRE-COBALT - COMPLEXE EXPLOITÉ PAR L'ACTIVITÉ MINIÈRE ARTISANALE / COPPER-COBALT ROCK OUTCROP - ARTISANAL MINING COMPLEX
- STEPPE-SAVANE SUR SUBSTRAT CUPRO-COBALTIFÈRE / COPPER-COBALT STEPPE-SAVANNA
- FORÊT DE MIOMBO / MIOMBO WOODLAND
- FORÊT DE MIOMBO DÉGRADÉE / MIOMBO WOODLAND DEGRADED
- FORÊT GALERIE / GALLERY FOREST
- ZONE HUMIDE / WETLAND
- MOSAÏQUE AGRICOLE / AGRICULTURAL MOSAIC
- ANCIENNE JACHÈRE / OLD FALLOW FIELD
- AÉROPORT / AIRFIELD
- PERTURBATION / DISTURBANCE
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE 1:90000 KILOMÈTRES
SCALE 1:90000 KILOMETERS

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

ZONE LOCALE D'ÉTUDE POUR L'ÉVALUATION DE BRUIT ET VIBRATION / NOISE AND VIBRATION ASSESSMENT STUDY AREAS

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035		ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN		REV. 0
DESSIN / DESIGN	JC	03 Apr. 2006		
GIS / SIG	TN	03 Jan. 2007		
VÉRIFIÉ / CHECK	MR	01 Nov. 2006		
APPROUVÉ REVIEW	MR	01 Nov. 2006		

FIGURE: C1.2-1

The two-kilometer radius for stationary noise sources was based on the result of a preliminary noise study for the processing plant site. This study indicated that a 1.3-kilometer radius is the distance at which noise sources from the processing plant site will diminish to an acceptable level. The radius distance of two kilometers was then assumed to include all the noise-sensitive receptors potentially affected by project activity.

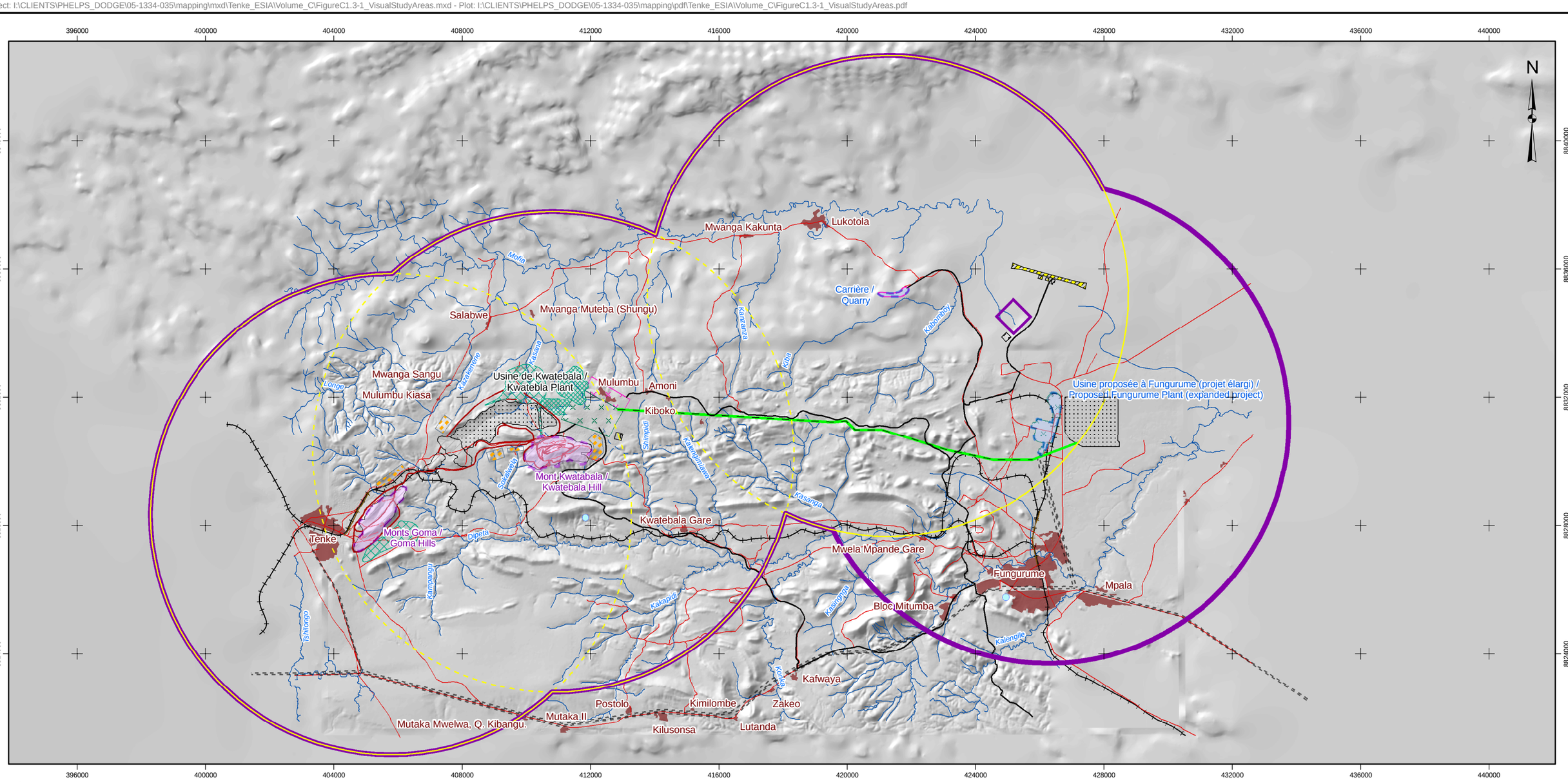
The vibration study focuses on the blast activities in the mine site and the limestone quarry. The vibration study assesses all structures within a one-kilometer radius of the mine site and the quarry site boundary (Figure C1.2-1).

C1.3 VISUAL AESTHETICS

The visual aesthetics assessment study areas were based on the viewshed of each project component. The viewshed is the area from where the current landscape, or the future landscape, plus project facilities (e.g., waste rock facilities or processing plant stacks) can be seen.

The visual aesthetics assessment shows that the industrial mining activities planned by TFM may typically cause visual impacts over distances of approximately seven to eight kilometers from the location of the facility. The visual impact (visual contrast) of an object diminishes quickly as the distance between the observer and the object increases. This inverse relationship is well recognized in visual analysis literature (e.g., Hull and Bishop 1988). The principle is graphically illustrated in Figure C2.5-1. The impact of an object in the foreground of a scene (0 to 800 meters) is greater than the impact of the same object in the middle ground of the scene (800 meters to 5 kilometers), which, in turn, is greater than the impact of the object in the background of the scene (greater than five kilometers).

In hilly terrain a development such as a mine or processing plant begins to blend into the background beyond seven or eight kilometers. At this distance the visual impact becomes insignificant. The maximum distance from the mine and associated major infrastructure at which visual impact could be an important factor has been set to 7.5 kilometers for the purposes of the ESIA. The assessment LSA for visual aesthetics is considered to be areas within 7.5 kilometers of the Kwatebala pit and processing plant as well as the Goma pits (Figure C1.3-1). The assessment RSA was considered to include these areas plus areas within 7.5 kilometers of the potential future plant north of Fungurume.



LÉGENDE / LEGEND

- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- SECTEURS DU PROJET MINIER PROPOSÉ / PROPOSED MINING PROJECT AREAS
- SECTEURS DU PROJET PROPOSÉ / PROPOSED PROJECT AREAS
- ZONE D'ÉTUDE LOCALE DE L'ESTHETIQUE VISUEL / REGIONAL STUDY AREA - VISUAL ASTHETICS
- ZONE RÉGIONALE D'ÉTUDE DE L'ESTHETIQUE VISUEL / LOCAL STUDY AREA - VISUAL ASTHETICS

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE L'IMPLANTATION FUTURE / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE 1:120000 KILOMÈTRES
SCALE 1:120000 KILOMETERS

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

ZONE D'ÉTUDE DE L'ÉVALUATION VISUELLE (ESTHÉTIQUE) / VISUAL AESTHETICS ASSESSMENT STUDY AREAS

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	GJ	22 Jun. 2006		
GIS / SIG	TN	03 Jan. 2007		
VÉRIFIÉ / CHECK	MR	01 Nov. 2006		
APPROUVÉ REVIEW	MR	01 Nov. 2006		

FIGURE: C1.3-1

C1.4 GROUNDWATER

The groundwater assessment for the RSA covers the general area between Tenke and Fungurume (Figure C1.4-1). The southern boundary is several kilometers to the south of the Dipeta River valley. The northern boundary is some six to seven kilometers north of the Kwatebala Hill and the proposed tailings storage facility. The RSA includes the Kazakenene drainage and other tributaries of the Mofia River.

The boundaries of the assessment LSA are shown in Figure C1.4-1. The LSA is centered on the Kwatebala deposit and the associated mine infrastructure. Impacts to groundwater from the project are expected to occur primarily within this area, although there will likely be some minor impacts outside this area.

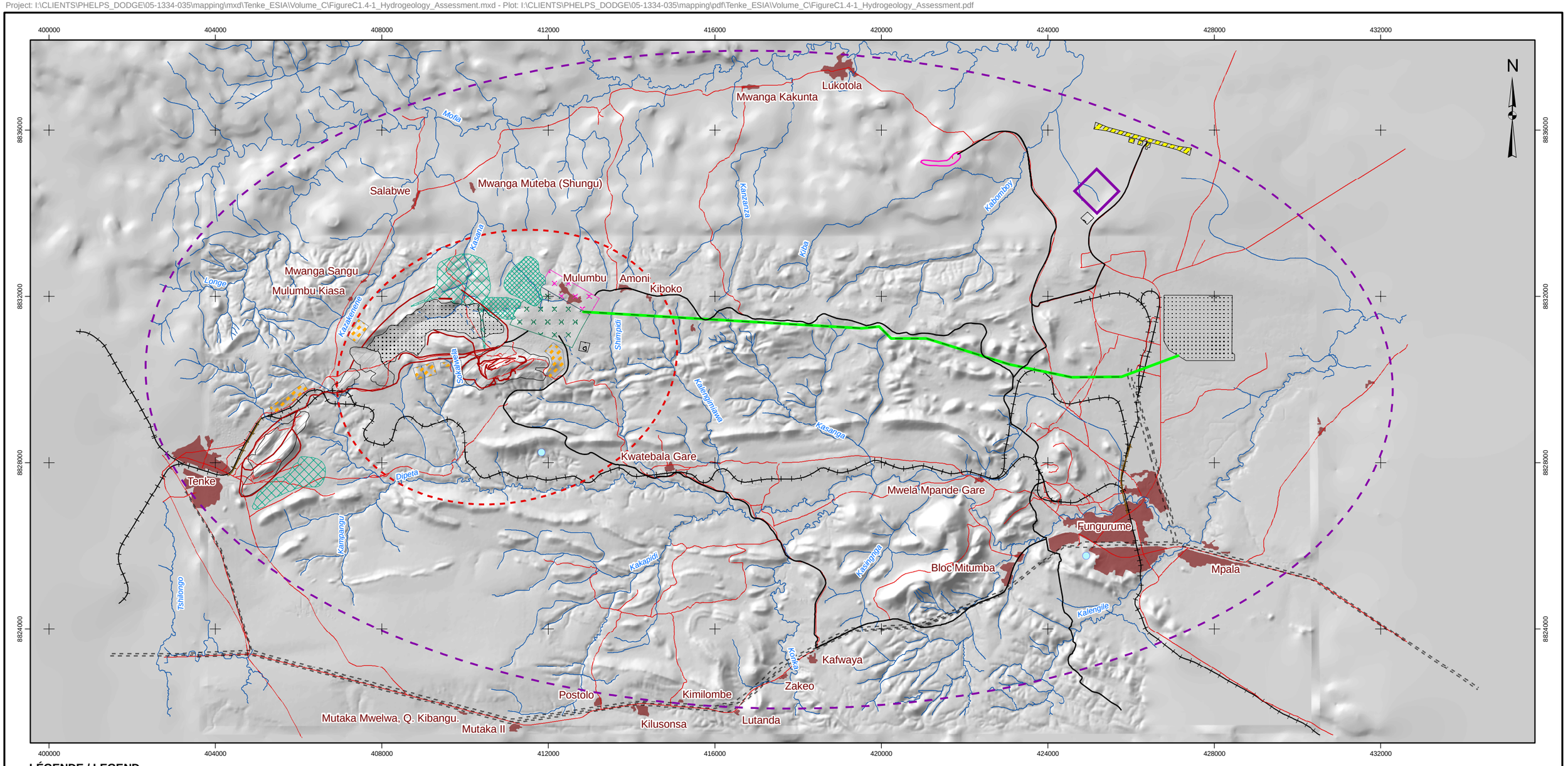
C1.5 HYDROLOGY, WATER QUALITY AND AQUATIC RESOURCES

The assessment RSA for surface water hydrology, water quality and aquatic resources covers:

- Portions of the Mofia and Dipeta river catchment (399 and 345 square kilometers, respectively)[1].
- A small portion of the Tshilongo River catchment (45 square kilometers) near Tenke. Proposed and potential future mining activities in the projects concession area will occur within these areas (Figure C1.5-1). Population growth at Tenke and Fungurume has the potential to impact the upper Tshilongo River catchment and the Dipeta River, respectively.

The Dipeta River flows generally from west to east and drains the southern regions of the concession area. The Mofia River flows generally from west to east and drains the northern regions of the concession area. The Tshilongo River flows generally northwards, just to the west of Tenke.

[1] Note: The entire Mofia and Dipeta river catchments are much larger; only those portions potentially affected by the project are included in the assessment RSA.



LÉGENDE / LEGEND

- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- ZONE D'ÉTUDE LOCALE / LOCAL STUDY AREA
- ZONE D'ÉTUDE RÉGIONALE / REGIONAL STUDY AREA

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE L'IMPLANTATION FUTURE / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE 1:90000 KILOMÈTRES
SCALE 1:90000 KILOMETERS

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

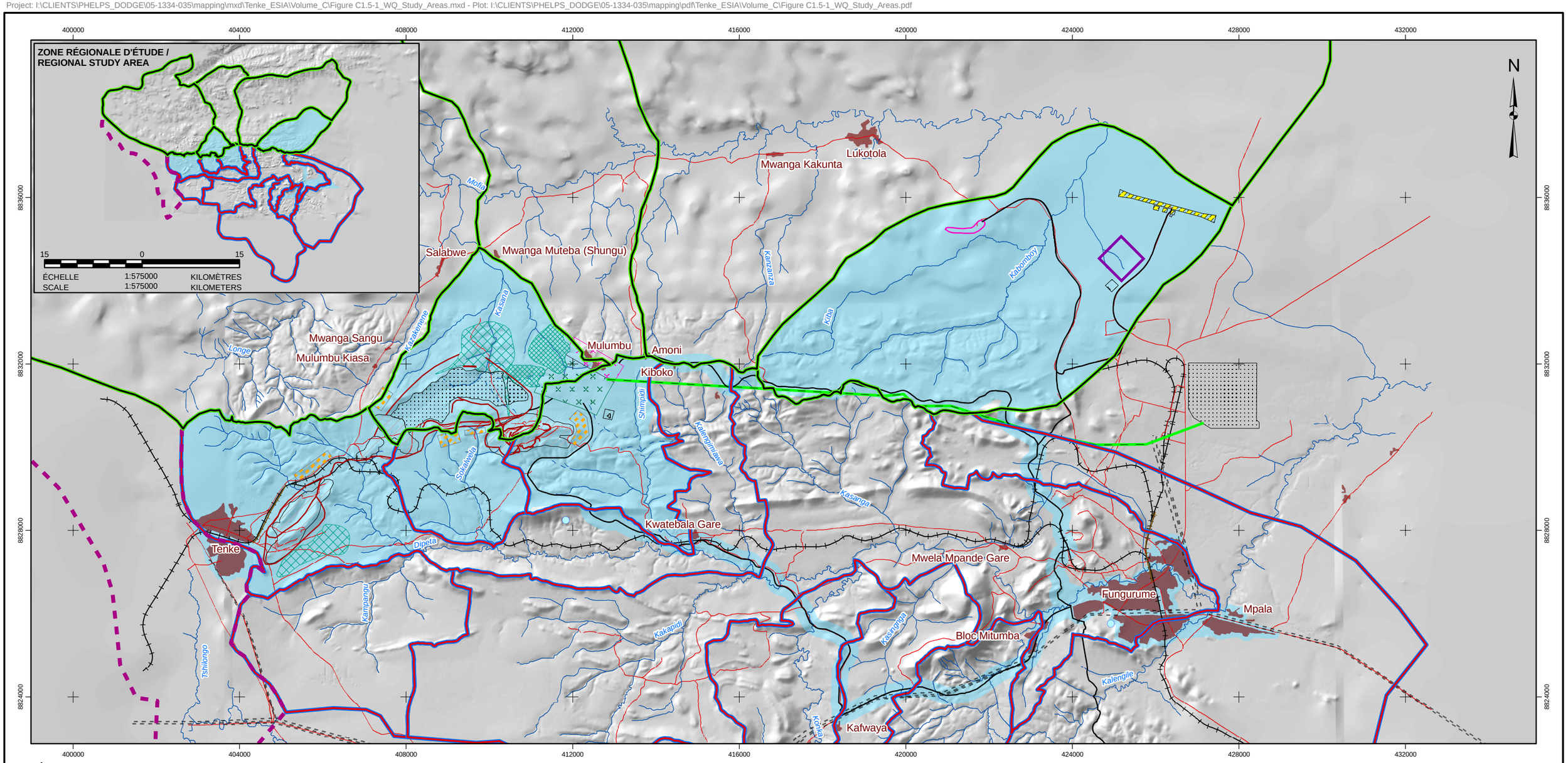
TITRE / TITLE

ZONES D'ÉTUDE DE L'HYROGÉOLOGIE / HYDROGEOLOGY ASSESSMENT STUDY AREAS

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN — REV. 0
DESSIN / DESIGN	GJ	22 Jun. 2006	
GIS / SIG	TN	04 Jan. 2007	
VÉRIFIÉ / CHECK	MR	20 Oct. 2006	
APPROUVÉ / REVIEW	MR	20 Oct. 2006	

FIGURE: C1.4-1



LÉGENDE / LEGEND

- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- ZONES D'ÉTUDE HYDROLOGIE, QUALITÉ DE L'EAU ET RESSOURCES AQUATIQUES / HYDROLOGY, WATER QUALITY AND AQUATIC RESOURCES STUDY AREAS

BASSINS VERSANTS / CATCHMENTS

- DIPETA
- MOFIA
- TSHILONGO

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE L'IMPLANTATION FUTURE / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3
ÉCHELLE 1:90000 KILOMÈTRES
SCALE 1:90000 KILOMETERS

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

ZONES D'ÉTUDE HYDROLOGIE, QUALITÉ DE L'EAU ET RESSOURCES AQUATIQUES / HYDROLOGY, WATER QUALITY AND AQUATIC RESOURCES ASSESSMENT STUDY AREAS

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	TR	15 May 2006		
GIS / SIG	TN	04 Jan. 2007		
VÉRIFIÉ / CHECK	MR	20 Oct. 2006		
APPROUVÉ / REVIEW	MR	20 Oct. 2006		

FIGURE: C1.5-1

The Dipeta River is fed by several tributaries that flow generally northwards into the Dipeta River, through the concession area. These main tributaries include the Konka, Kakapidi, Kampangu, Kasingnga, Kanwesi, Kamakanda and Kalengile rivers. Three main tributaries flow generally southwards towards the Dipeta River. These are the Shimpidi, Sokalwela and Kalengimiawa rivers.

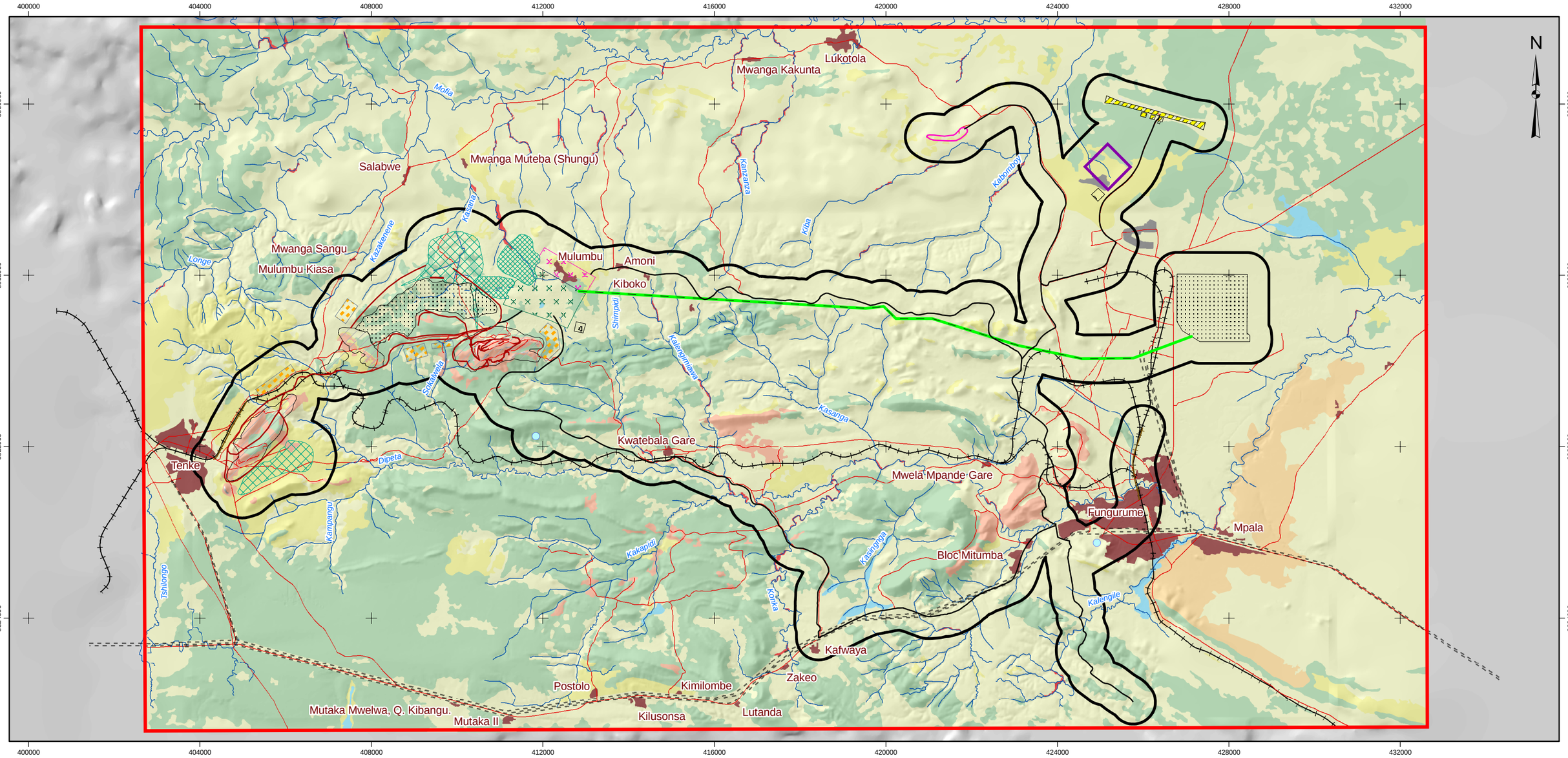
The Mofia River is fed by several tributaries that flow generally northwards through the northern extents of the concession area. These tributaries include the Longe, Kiomba, Kasana, Kazakenene and Kabomboy rivers.

The assessment LSA of 130 square kilometers covers the area where mining and its associated activities have the potential to directly impact surface water (Figure C1.5-1). The mine site is located in the upper Dipeta, Shimpidi, Sokalwela and Kasana catchments, while the limestone quarry, airstrip and construction camp/permanent village will be located in the Kabomboy catchment. Construction and operation of access roads have the potential to cause localized effects in several other subcatchments of the Mofia and Dipeta rivers, thus these roads and a buffer zone on each side are included in the LSA (Figure C1.5-1).

C1.6 TERRESTRIAL

The terrestrial assessment RSA contains the mine and its associated facilities as well as areas where future development is likely to occur. Expansion of the TFM project may include construction of a processing plant north of Fungurume and mining of the Fungurume hills. The assessment RSA was thus determined to be a 16 by 30 kilometer rectangular area surrounding the ore bodies between Tenke and Fungurume (Figure C1.6-1).

The terrestrial assessment LSA was designed to capture the direct effects of the physical footprint of the mine and its alternatives on terrestrial resources topography, geomorphology, soil, flora, fauna and biodiversity. The assessment LSA also attempts to capture the immediate indirect effects of mining activities (e.g., fugitive dust, changes in surface water flow or disturbance of wildlife). The LSA is large enough to predict the potential effects of the mine on the soil, vegetation and the home ranges of animals living within or next to the project area.



LÉGENDE / LEGEND

- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- ZONE D'ÉTUDE LOCALE - TERRESTRE / LOCAL STUDY AREA - TERRESTRIAL
- ZONE D'ÉTUDE RÉGIONALE / REGIONAL STUDY AREA

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- PILE DE STOCKAGE DE MINERAI À FAIBLE TENEUR / LOW GRADE STOCKPILE
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

COUVERTURE VÉGÉTALE / UTILISATION DU TERRAIN / LANDCOVER

- AFFLEUREMENT ROCHEUX DE MINERAI CUIVRE-COBALT - COMPLEXE EXPLOITÉ PAR L'ACTIVITÉ MINIÈRE ARTISANALE / COPPER-COBALT ROCK OUTCROP - ARTISANAL MINING COMPLEX
- STEPPE-SAVANE SUR SUBSTRAT CUPRO-COBALTIFÈRE / COPPER-COBALT STEPPE-SAVANNA
- FORÊT DE MIOMBO / MIOMBO WOODLAND
- FORÊT DE MIOMBO DÉGRADÉE / MIOMBO WOODLAND DEGRADED
- FORÊT GALERIE / GALLERY FOREST
- ZONE HUMIDE / WETLAND
- MOSAÏQUE AGRICOLE / AGRICULTURAL MOSAIC
- ANCIENNE JACHÈRE / OLD FALLOW FIELD
- AÉROPORT / AIRFIELD
- PERTURBATION / DISTURBANCE
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE / SCALE 1:90000 1:90000 KILOMÈTRES / KILOMETERS

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

ZONE D'ÉTUDE LOCALE DE L'ÉTUDE TERRESTRE / TERRESTRIAL RESOURCES ASSESSMENT STUDY AREAS

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	DN	03 Apr. 2006		
GIS / SIG	TN	04 Jan. 2007		
VÉRIFIÉ / CHECK	MR	20 Oct. 2006		
APPROUVÉ / REVIEW	MR	20 Oct. 2006		

FIGURE: C1.6-1

The terrestrial assessment LSA is approximately 142 square kilometers in size. It is based on the spatial extent of the footprint, including alternative project elements, and to include potential immediate indirect effects on the receiving environment (Figure C1.6-1). All project components were buffered by 500 meters. In the case of roads, this created a study area corridor about 1,000 meters wide (500 meters on either side of the road). After this initial buffering exercise, the LSA boundary was "smoothed" to include narrow strips of land or small holes in the buffered coverage.

C1.7 PROTECTED AREAS

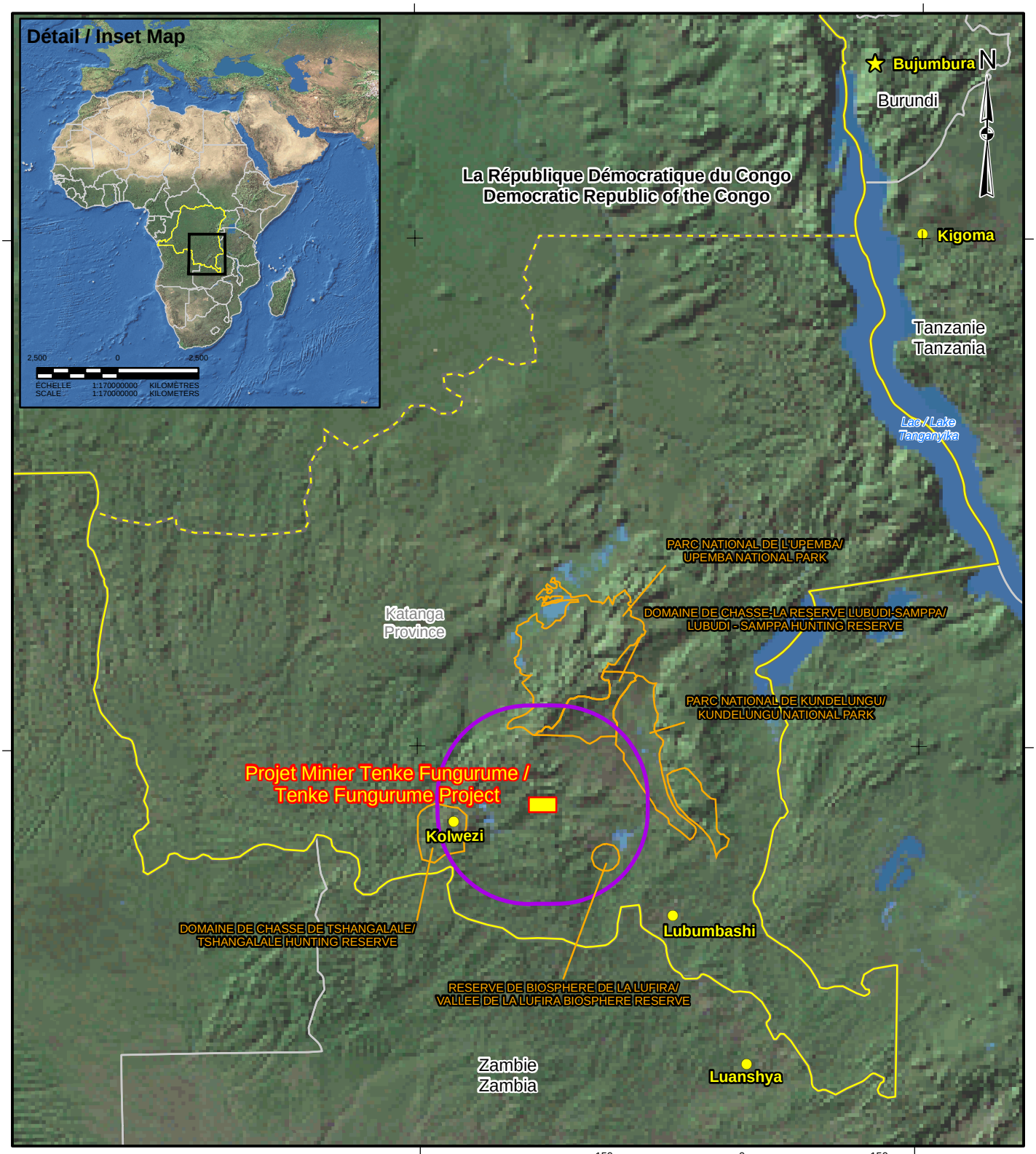
An assessment RSA for protected areas in parts of the Democratic Republic of the Congo (DRC) within 100 kilometers of the TFM project was assessed in order to provide a basis to evaluate potential indirect impacts of the project (Figure C1.7-1). An assessment LSA, including all potential project impact areas, plus a 500-meter buffer zone (equivalent to the terrestrial study area), was also assessed to provide a basis to evaluate potential direct impacts of the project (Figure C1.6-1).

C1.8 SOCIO-ECONOMICS

Socio-economic assessment study areas include consideration of potential effects at the national, regional and local levels. The assessment RSA for socio-economics includes the nation (for macro-economic impacts at the level of the country), Katanga Province and the Kolwezi District (Figure C1.8-1). The socio-economic assessment LSA includes the footprint of the mine and its area of direct and indirect influence, including the adjoining towns that will be most affected (e.g., Tenke and smaller villages) (Figure C1.8-2). The assessment LSA falls within the jurisdiction of the Kolwezi District.

In addition to the urban areas of Tenke and Fungurume, 39 villages and hamlets fall within the assessment LSA. The LSA includes the following five regions:

- Urban Tenke and Fungurume.
- Suburban villages of Mpala and Bloc Mitumba.
- Villages along the national road between Fungurume and Tenke.
- Villages directly between the railroad and the direct concession area including: Mwela Mpande Gare, Kwatebala Gare, villages between Kasanga and Mulumbu and villages along the Tenke to Salabwe Road.
- Northern villages around the limestone quarry site and the airport and Lukotola.



LÉGENDE / LEGEND

- CAPITALE / CAPITAL
- VILLE PRINCIPALE / MAJOR CITY
- KATANGA PROVINCE
- LA RÉPUBLIQUE DÉMOCRATIQUE DU CONGO / DEMOCRATIC REPUBLIC OF THE CONGO
- PROJET MINIER TENKE FUNGURUME / TENKE FUNGURUME PROJECT
- ZONE RÉGIONALE D'ÉTUDE POUR L'ÉVALUATION DES AIRES PROTÉGÉES / PROTECTED AREAS - REGIONAL STUDY AREA
- AIRES PROTÉGÉES : ZONE D'ÉTUDE RÉGIONALE / REGIONAL STUDY AREA - PROTECTED AREA

RÉFÉRENCE / REFERENCE

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Protected areas Reference / Reference Aires Protegees: Sites du Partimoine Mondial Et Aires Protegees: Republique Democratique du Congo. 2006. Universite Catholique de Louvain.
Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

ZONE RÉGIONALE D'ÉTUDE POUR L'ÉVALUATION DES AIRES PROTÉGÉES / PROTECTED AREAS ASSESSMENT STUDY AREAS

Golder Associates
Calgary, Alberta

N° projet / project no. 05-1334-035.9300		Échelle telle qu'indiquée / Scale as Shown	REV. 0
DESSIN / DESIGN	GE	20 Mar. 2006	
SIG / GIS	TN	04 Jan. 2007	
VÉRIFIÉ / CHECK	MR	01 Nov. 2006	
APPROUVÉ / REVIEW	MR	01 Nov. 2006	

FIGURE: C1.7-1

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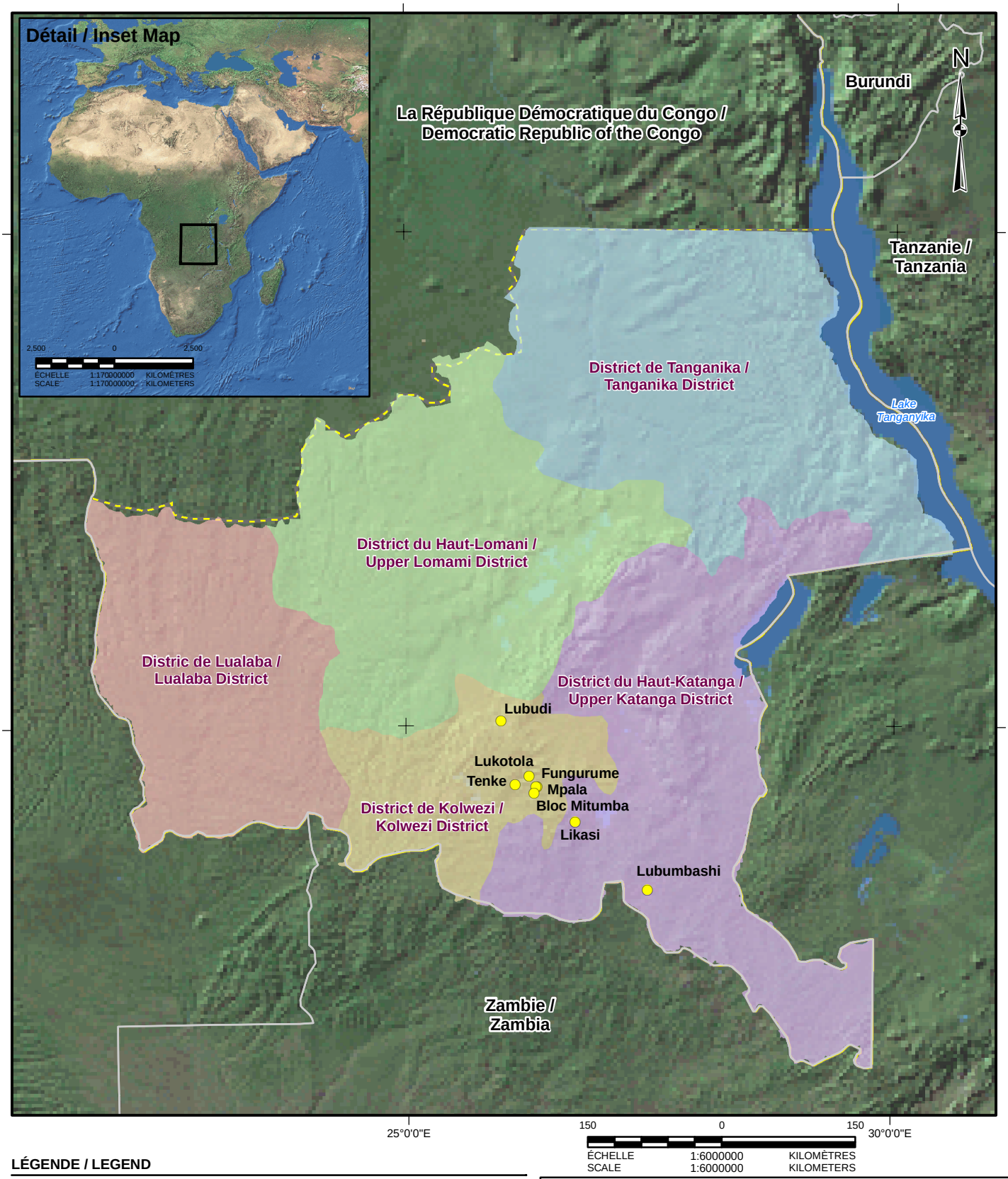

LÉGENDE / LEGEND

- VILLAGE
- PROVINCE DU KATANGA / KATANGA PROVINCE
- LA RÉPUBLIQUE DÉMOCRATIQUE DU CONGO / DEMOCRATIC REPUBLIC OF THE CONGO
- DISTRICT DU HAUT-KATANGA / UPPER KATANGA DISTRICT
- DISTRICT DU HAUT-LOMANI / UPPER LOMANI DISTRICT
- DISTRICT DE KOLWEZI / KOLWEZI DISTRICT
- DISTRICT DE LUALABA / LUALABA DISTRICT
- DISTRICT DE TANGANIKA / TANGANIKA DISTRICT

RÉFÉRENCE / REFERENCE

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Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

ZONES D'ÉTUDE
SOCIO-ÉCONOMIQUE AU NIVEAU NATIONAL ET PROVINCIAL
/ SOCIO-ECONOMIC NATIONAL AND PROVINCIAL STUDY AREAS

Golder Associates
Calgary, Alberta

N° projet / project no. 05-1334-035.9300			Échelle telle qu'indiquée Scale as Shown	REV. 0
DESSIN / DESIGN	LH	22 Jun. 2006		
SIG / GIS	TN	04 Jan. 2007		
VÉRIFIÉ / CHECK	MR	12 Jul. 2006		
APPROUVÉ REVIEW	MR	31 Jul. 2006		

FIGURE: C1.8-1

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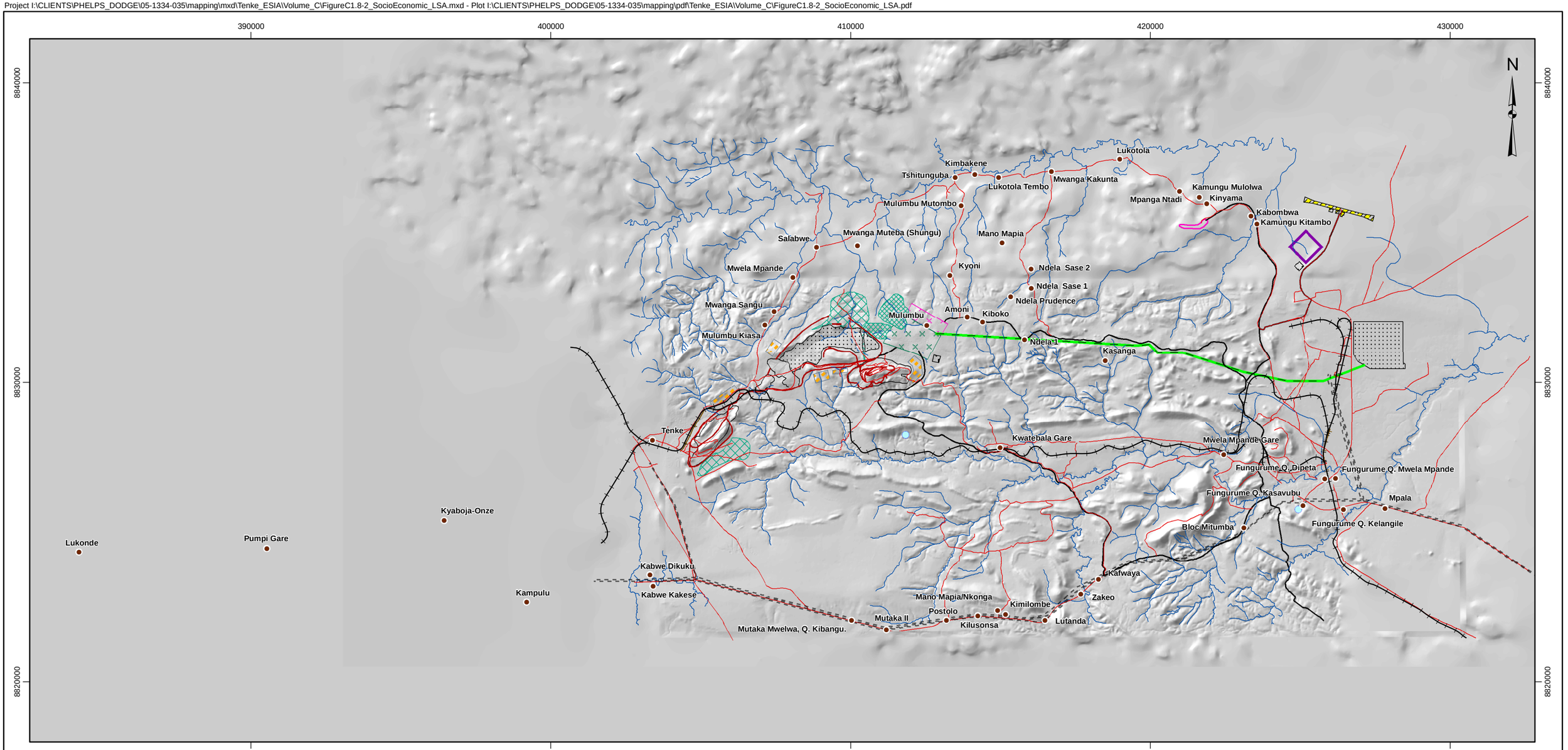


LÉGENDE / LEGEND

- VILLAGE
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

4 0 4

ÉCHELLE 1:125000 KILOMÈTRES
SCALE 1:125000 KILOMETERS

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE **ZONE D'ÉTUDE LOCALE DES ASPECTS SOCIO-ÉCONOMIQUES / SOCIO-ECONOMIC LOCAL STUDY AREA**

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	LH	23 May 2006		
GIS / SIG	TN	04 Jan. 2007		
VÉRIFIÉ / CHECK	MR	20 Oct. 2006		
APPROUVÉ / REVIEW	MR	20 Oct. 2006		

FIGURE: C1.8-2

All towns shown within Figure C1.8-2 are within the socio-economic LSA. Background information on land use was not available for some of the outlying towns.

C1.9 CULTURAL HERITAGE

The assessment RSA for cultural heritage follows the assessment RSA for terrestrial resources and includes all project expansion areas. The assessment RSA for culture heritage is a 16 by 30 kilometer rectangular area (Figure C1.6-1).

The assessment LSA for cultural heritage follows the terrestrial assessment LSA for the project (Figure B1.6-1). This LSA is about 142 square kilometers in size and has a 500-meter buffer zone surrounding all project aspects and alternatives.

C2.1 TOPOGRAPHY AND GEOMORPHOLOGY

C2.1.1 Introduction

This section presents the environmental and social impacts assessed for the effects of the Tenke Fungurume Mining (TFM) project on topography and geomorphology. The information presented meets the requirements of the TFM project's terms of reference (Section E8) and includes details on:

- Potential issues regarding changes to topography and geomorphology.
- Project activities that may affect topography and geomorphology.
- Mitigations measures incorporated in the project design to minimize environmental and social impacts.
- Impact assessment approach and results for key topography and geomorphology issues.
- Sustainability assessment approach and results for key topography and geomorphology issues.
- Cumulative assessment approach and results for key topography and geomorphology issues.
- Identified measures relating to topography and geomorphology to promote long-term economic and social sustainability in the project area.

This section is organized as follows:

- Section C2.1.2 describes the study areas.
- Section C2.1.3 discusses the approaches and results for the impact and the sustainability assessments.
- Section C2.1.4 provides the cumulative effects assessment.
- Section C2.1.5 discusses the conclusions of the assessment.

Baseline information concerning topography and geomorphology has been provided in Section B2.1.

A glossary of terms and acronyms used is provided at the back of this volume.

C2.1.2 Study Areas

The study areas for the topography and geomorphology impact assessment are the same as those for the topography baseline.

The impact assessment Regional Study Area (RSA) is a rectangle approximately 16 by 30 kilometers in size (Figure C1.6-1). The RSA contains the impact assessment Local Study Area (LSA), numerous urban settlements (including Fungurume, Tenke, Mulumbu and Lukotola) and various infrastructure developments (including an airstrip, powerlines, roads and railway tracks). The RSA contains nearly the entire Dipeta catchment and the southern portion of the Mofia catchment. The RSA includes areas likely to experience indirect impacts or downstream effects from project development within the LSA.

The topography and geomorphology LSA is located between the towns of Tenke and Fungurume and is made up of the ore body complex (Kwatebala Hill, Goma hills and the Kavifwafwaulu [Fwaulu] hills), the mine and its facilities, the main access road, and all other infrastructure relating to the project. The LSA also includes the site of the proposed limestone quarry north of Fungurume (Figure C1.6-1). The LSA represents the area predicted to have the highest direct impact due to project development.

C2.1.3 Impact Assessment

C2.1.3.1 Issue Scoping

The anticipated key issues relating to topography and geomorphology are:

- Initial removal and disturbance of unique or important topographic features important for social or biological reasons.
- Changes in the landscape and underlying geomorphology (shape, slope and elevation of land features) which may represent important issues to people or the environment.

A number of issues relating to topography and geomorphology were noted during the public consultation process (Section A6). These include:

- Concern that removal of the entire Kwatebala Hill over time will change the area's visual character.
- Concerns that changes in topography such as roadway construction may affect economic development, particularly the movement of agricultural products to market.

- The way future socio-economic benefits from the land may be impacted by topographic changes (including effects on agricultural production, and the loss of the artisanal mining economy).

This section of the TFM project's environmental and social impact assessment (ESIA) focuses directly on the specific topographic and geomorphic changes, but other ESIA sections address the implications of those changes. ESIA sections on visual aesthetics, hydrology, hydrogeology, land use, socio-economics and closure all discuss the implications of changes to topography and geomorphology.

C2.1.3.2 Key Questions and Indicators

Two key questions were established to determine the environmental impact of the TFM project on topography and geomorphology. The key questions listed in Table C2.1-1 address the aspects of impact assessment and sustainability assessment for topography and geomorphology.

Table C2.1-1 Key Questions for Topography and Geomorphology

Impact Assessment
TG-1 What effect will the project have on topography and geomorphology?
Sustainability Assessment
TG-2 How can the project influence topography and geomorphology to have a long-term positive effect?

Indicators relating directly to topography include slopes, heights of features, and variability of terrain. Topographically unusual terrain is also included. Changes in these indicators are discussed in this section. Indicators relating to visual appearance, socio-economic effects and effects on water flow are addressed in those ESIA sections (see Sections C2.5, C4.1 and C2.11).

C2.1.3.3 Assessment Criteria

Assessment criteria for topography and geomorphology are presented in Table C2.1-2. The screening system for sustainability consequence is provided in Section A5.

Table C2.1-2 Impact Description Criteria for Topography and Geomorphology

Direction[a]	Magnitude[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
neutral: no change in topography **negative:** a change in topography that affects function for human or biological services in a way not demonstrably positive **positive**: a change in topography that improves 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:** less than 3 years **medium-term:** 3 to 20 years **long-term:** more than 20 years	**reversible:** impacts can be slightly to completely repaired or remedied **irreversible:** impacts cannot be repaired or remedied	**low:** occurs once or rarely **medium:** occurs intermittently **high:** occurs continuously

[a] Direction: positive or negative effect for measurement indicators as defined for the specific component.

[b] Magnitude: degree of change to analysis indicator.

[c] Geographic Extent: area affected by the impact.

[d] Duration: length of time over which the environmental effects occurs. Considers a two-year construction period and a 20-year operations period.

[e] Reversibility: effect on the resource (or cannot be reversed).

[f] Frequency: how often the impact occurs.

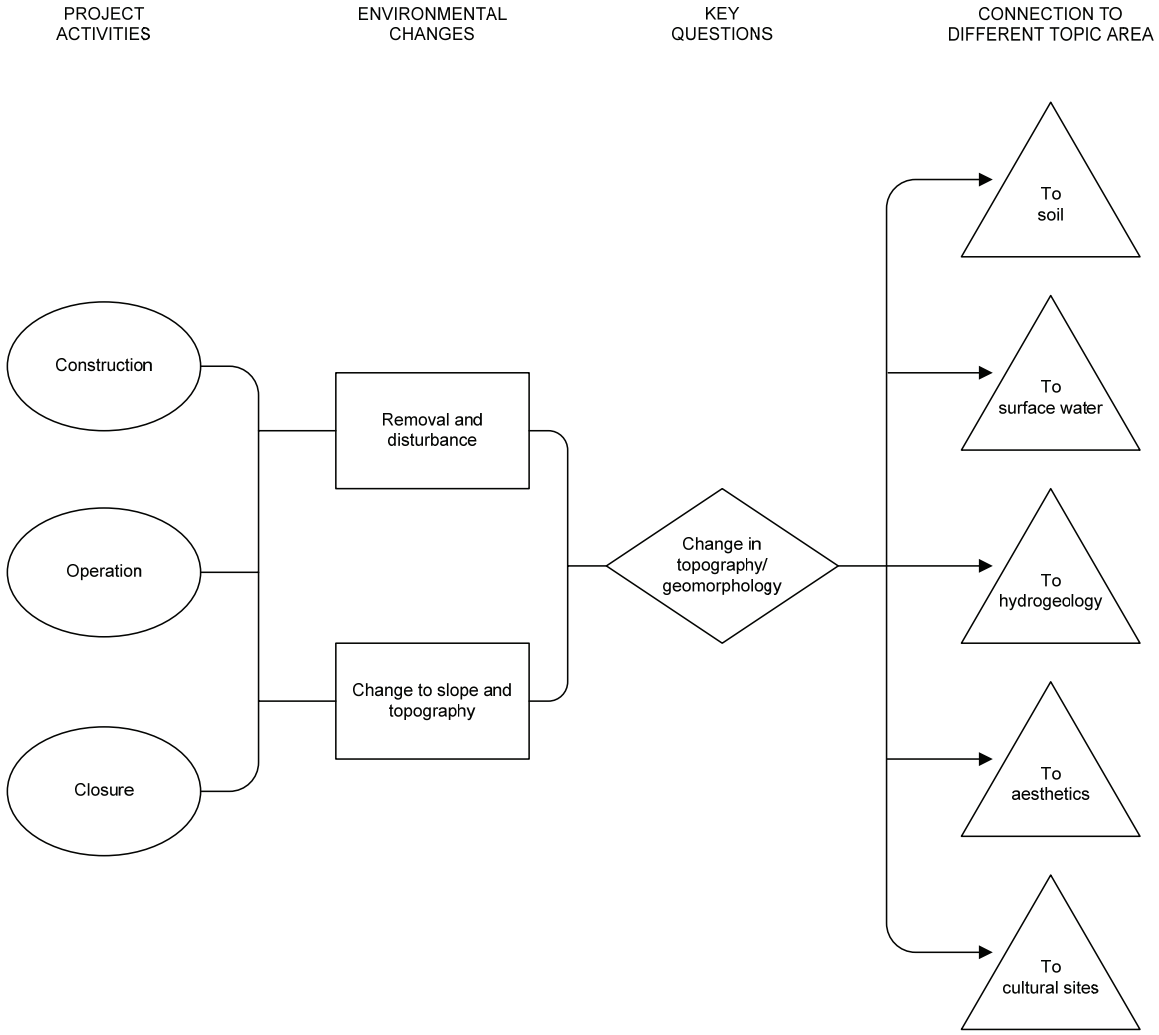
C2.1.3.4 Key Question TG-1

Key question TG-1 is: What effect will the project have on topography and geomorphology?

Linkage Evaluation

A cause and effect diagram for topography and geomorphology is presented in Figure C2.1-1. As earthmoving activities during the construction, operations and closure phases of the TFM project have the potential to affect topography and geomorphology, this linkage is valid.

Figure C2.1-1 Topography and Geomorphology Linkage Diagram



Assessment Methods

Plans for mine, road and facility development (Section A4) were reviewed in the context of known baseline conditions for topography and geomorphology. Professional experience was used to develop an understanding of the potential effects of the TFM project, specifically in relation to changes in topography and geomorphology generally caused by mining, processing plant sites, waste rock facilities, quarries and linear developments, such as roads. Preliminary closure plans (Section D5) and goals to mitigate (minimize) effects over the long term, were used to develop an assessment of long-term impacts.

Mitigation

The following mitigation measures will be employed to minimize impacts on topography and geomorphology:

- During construction, operations and closure, erosion control measures will be applied as described in Section C2.4 (soils). Reducing surface effects on soils, such as erosion, has the added benefit of reducing formation of gulleys (trenches) that would represent an undesirable effect on topography.
- During construction, operations and the beginning of the closure phase, water management systems, as described in Section C2.12 (water quality) will be used in the mine areas to minimize silt disturbance, silt suspension and silt deposits in downstream watercourses. Although mainly related to water quality effects, this mitigation also limits changes in the watercourse topography that could occur with the build-up of finely eroded materials.
- During operations, mine slopes will be engineered and constructed so that they are stable. Safety procedures will be followed to ensure that on-site staff and the general public are not placed at risk due to steep topography which will be in place temporarily during operations.
- Reclamation will occur progressively where feasible, during the operations phase, and will be completed in the closure phase. Reclamation will help to reduce the post-closure slope changes that would occur at mine and quarry sites during operations will help enhance topographic diversity and will help restore geomorphic terrain that may have been lost during operations. Public consultation regarding appropriate land uses will help ensure the reclaimed landscape is appropriate for future land use activities.

Results

The topography of the mine areas will be most affected. The ore bodies will affect Kwatebala, Goma and Fwaulu hills, ultimately removing most or all of these prominent topographic features, while increasing internal mine slopes (highwalls up to 155 meters high will have slopes of about 39 degrees).

The rock will be mined in five-meter benches. Associated with mine areas, waste rock facilities will be created next to mining areas. At Kwatebala Hill, the maximum height of the main waste rock facility will be 100 meters, with a side slope ratio of 1:1.5 (33.7 degrees). The waste rock stockpile east of Goma hills is expected to be about 55 meters high. These two waste rock stockpiles will represent locally prominent topographic features.

Other stockpiles for low-grade ore will be built on top of the waste rock facilities located near the processing plant. This ore will be processed following processing of the higher grade ore. Additional planned stockpiles include:

- Storage areas for materials such as lime and sulfur.
- Short-term ore stockpiles.
- Temporary topsoil stockpiles of smaller sizes.

At closure, highwalls along the edges of mine pits will be flattened, making topography of mine areas easy for people and equipment to move across. Lower benches of mine pits will be left as is, as the mine pits will be allowed to fill with water at closure. Closure of rock stockpiles in mine areas will involve:

- Grading to pre-determined slopes for safety and drainage.
- Compacting the surface of the piles for safety and strength.
- Constructing of rock-lined channels to direct runoff water to local watercourses.
- Replacing topsoil on the tops of the stockpiles. The topsoil will be reseeded with native grasses and forbs (herbs), or be returned to rain-fed agricultural use.
- The sides of the stockpiles will be left as exposed rock.

The topography of the quarry area will be affected in a similar way to the mine areas, but on a smaller scale. Quarry rock faces will be mined and material will be removed (about 90,000 tonnes of material annually), reducing the size of the quarry hill. Baseline quarry topography includes moderately steep rock faces,

which will be mined during the operations phase of the TFM project. At closure, these rock faces will be left in place for potential future operation of the quarry.

The topography associated with linear features such as new or rebuilt roads for the TFM project will be altered slightly in some areas to create a flat linear route of adequate size. Side cuts in hills will be made to create some linear features, but minimal impacts are expected due to the use of appropriate reclamation techniques. The topography of the plant site, camp site and other new infrastructure facilities will be flattened to accommodate buildings. Storage areas for materials such as lime and sulfur will be developed, but these will appear small when compared with other topographic features in the area. Because relatively flat sites have been selected for these facilities, a limited topographic impact will be observed. At closure, process materials will be removed from the site.

The topography of the tailings storage facility will be altered with the development of a dam structure with a slope of about 14 degrees, and the gradual filling of the pond area to create a relatively flat-topped surface. The embankment (dam) will be constructed primarily of waste rock and will go through a phased development over the course of the TFM project's operations. At closure, the surface of the tailings storage facility will be left in place but will be covered with a layer of waste rock and a layer of salvaged topsoil, allowing for a small degree of local topographic diversity to be established. Revegetation will occur to minimize erosion from the sides and surface of the tailings storage facility.

Impact Analysis

During construction, topographic impacts will occur at the mine and quarry areas, along new road routes, at the tailings storage facility and at the processing plant site. Most impacts will initially consist of leveling of the terrain and will be very small. These impacts are considered negligible in magnitude, local in geographic extent, long-term in duration (because they make permanent changes to the landscape) and of medium frequency during the TFM project period. Impacts on topography and geomorphology will not be reversed. The environmental consequence of these effects will be negligible (Table C2.1-3).

Table C2.1-3 Residual Impact Classification for Key Question TG-1

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question TG-1: What effect will the project have on topography and geomorphology?						
Construction Phase						
negative	negligible	local	long-term	irreversible	medium	negligible
Operation Phase						
negative	moderate	local	long-term	irreversible	medium	moderate
Closure Phase						
negative	moderate	local	long-term	irreversible	low	moderate

During operations, topographic impacts at the mine, quarry areas and tailings storage facility will increase over time. The mine will increase in size and depth, the quarry headwall will move over time and the tailings storage facility will increase in height. The waste rock facility and storage stockpiles (mainly those for lower grades of ore, as described above) will be built up. Locally, some topographic impacts will be very large, but in the context of the entire LSA the topographic and geomorphic impacts are more appropriately rated as moderate. On the basis of all planned topographic and geomorphic changes, impacts are considered moderate during operations within a local geographic extent. Effects on topography and geomorphology will be long term and mostly irreversible. The frequency of changes to topography and geomorphology will be medium during operations. The overall environmental consequence during operations is rated as moderate.

During the closure phase, reclamation will be completed, with some leveling and smoothing of topography, most notably at the mine areas. Permanent changes will remain at the site of the mine and quarry areas, tailings storage facility, processing plant facilities and along the edges of some linear developments, such as roads. Effects after closure will be moderate, local, long-term and irreversible, with a low frequency of impact. The overall environmental consequences at closure are rated as moderate.

These impact ratings do not specifically address the direct aesthetic, hydrology and social effects associated with such changes. These are discussed in the appropriate sections of this volume.

Prediction Confidence

The baseline status of topography and geomorphology in the LSA is well understood. Information concerning the effects of the mine and quarry areas,

tailings storage facility, plant site and other infrastructure is adequate to have a high confidence in the impact predictions in this section.

C2.1.3.5 Key Question TG-2

Key question TG-2 is: How can the project influence topography and geomorphology to have a long-term positive effect?

Assessment Methods

In general, assessment methods are the same for key questions TG-1 and TG-2. Plans for mine, road and facility development were reviewed in the context of known baseline conditions for topography and geomorphology. Professional experience was used to develop an understanding of the potential effects of the TFM project, specifically in relation to the long-term (post-closure) changes in topography and geomorphology caused by mining, processing plant sites, waste rock facilities, quarry and linear developments, such as roads. Key question TG-1 emphasizes potential negative effects of losses of existing topographic features while key question TG-2 emphasizes the potential long-term benefits of topographic changes in a socio-economic context.

Mitigation

The post-closure landscape will be developed with specific principles. Sites will be returned to a safe and stable condition with all steep slopes bermed and fenced. The sites will be returned to a topographic condition that will support, wherever feasible, a self-sustaining ecosystem compatible with the surrounding environment and post-mining land use. However, reclamation of the open pit mine is not considered practical at this time, and no commitments are being made to revegetate the highwalls. The social and economic implications of mine closure will be studied and appropriate transition strategies will be developed for the benefit of employees and the local community, as set out in the TFM project's reclamation and closure plan (Section D5). Based on the results of public input, consideration will be given to modifying closure plans to allow rapid integration of new or previously existing sustainable economic land uses.

TFM will evaluate the possibility of conserving some of the more outstanding geomorphology in the RSA based on the potential for future mineralization developments. This will be combined with the program for the protection of threatened plant species which is described in Section C3.1. The area four kilometers southwest of the TFM camp and north of Lutanda may be considered as a potential site, since it comprises an unusual horseshoe-shaped landform (Photograph C2.1-1).

Photograph C2.1-1 Horseshoe-Shaped Land Form Just North of Lutanda

Results

It is anticipated that, in the long term:

- Local areas will have changes in slopes.
- The height of geographic features, such as the hills being mined, will change.
- Topographic diversity, such as different patterns of slopes, will be created in some areas and very flat landscapes created in other areas.

Following reclamation, although topography will not be returned to the same condition it was in before the TFM project, the landscape can be developed to suit specific certain end land uses that will enhance socio-economic sustainability once the TFM project is complete. For example, flat areas left at the plant site may be used for ongoing industrial use or may be partly converted for

agriculture. Flat areas created for camps may be used for villages. Pit lakes developed in mine pits may have potential uses for the local population, depending on the results of water quality monitoring (Section B.2.3). Specific topographic features such as rocky hilltop areas may be left in place to sustain specific kinds of biological diversity.

Impact Analysis

The positive impacts that can occur for topography and geomorphology, in relation to longer-term sustainability, are projected to be moderate. Positive impacts will be confined locally within the LSA, will affect those individuals who can take advantage of the new topographic features for their benefit and be long-term in duration. The probability of successful enhancements to topography for sustainability is considered medium. Assuming that the unusual geomorphological feature south east of the TFM camp is conserved within the RSA, the sustainability consequence for the TFM project is rated as moderate (Table C2.1-4).

Table C2.1-4 Residual Impact Classification for Key Question TG-2

Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key Question TG-2: How can the project influence topography and geomorphology to have a long-term positive effect?				
moderate	a few people	long-term	medium	moderate

Prediction Confidence

The principles guiding long-term development of the post-closure landscape are designed to ensure that landscape will have sustainable socio-economic value to local populations. Because of the general nature of these principles, prediction confidence that positive benefits to the landscape for sustainability can ultimately be realized is rated as low to moderate.

Monitoring

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

C2.1.4 Cumulative Effects Assessment

Linkage Evaluation

Should the TFM project be expanded from 115,000 tonnes per year production to 400,000 tonnes per year, the physical extent of topographic modification would increase considerably with additional areas being mined and additional areas required for tailings storage facilities, waste rock facilities and processing plants.

Assessment Methods

Detailed plans for the additional development of the project to expand to 400,000 tonnes per year are not yet available. However, the general concept for such a development was reviewed in the context of known baseline conditions for topography and geomorphology. Professional experience was used to develop an understanding of the potential effects of an expanded TFM project, specifically in relation to the long-term (post-closure) changes in topography and geomorphology caused by mining, processing plant sites, waste rock facilities, the quarry and linear developments, such as roads. Principles developed for closure plans and other project goals to mitigate (minimize) long-term effects over the long term were considered in the assessment of long-term impacts.

Mitigation

In addition to mitigation as proposed for key question TG-1, an expended 400,000 tonnes per annum project would have to create a more detailed plan for watershed restoration, due to the greater level of impact on the Dipeta watersheds due to the project.

Results

The effects on topography and geomorphology with a larger, 400,000 tonnes per year project would be greater in magnitude than those predicted for key question TG-1, but the types of impacts expected would be similar. Changes in slopes and heights of existing landforms would be anticipated (principally those hills impacted directly by mining). New waste dumps would be developed, representing locally prominent topographic features, which in some cases would be temporary. Permanent effects would occur due to the development of new tailings storage areas. Three to four times the land area of the project would be affected in such a cumulative case, depending on economies of scale and advances in technology that might help to reduce this impact.

Impact Analysis

For the cumulative development case, impacts will occur across much of the LSA and likely in additional ore-bearing hills outside of the LSA, such as the Fungurume hills. The expanded TFM project would cover considerably more land area than those in the project case assessed under key question TG-1. The impacts for the cumulative case are predicted to be moderate to high in magnitude (following all mitigation including reclamation and closure), regional in geographic extent, long-term in duration (because they make permanent changes to the landscape) and of medium frequency during this period. Impacts will not be reversible. The consequence of these effects will be high (Table C2.1-5).

Table C2.1-5 Residual Impact Classification for the Cumulative Case

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question $TG_{(ce)}$-1: What effect will the project have on topography and geomorphology?						
negative	moderate to high	regional	long-term	no	medium	high

Prediction Confidence

The baseline status of topography and geomorphology in the LSA is well understood. Information concerning the effects of a larger, 400,000 tonnes per year project is limited, but a general understanding of the effects of such a project is in place. The prediction confidence for this assessment is rated as moderate.

C2.1.5 Conclusions

Residual impacts are summarized in Tables C2.1-3, C2.1-4 and C2.1-5.

Following mitigation, the TFM project will have a negligible environmental consequence for topography during the construction phase, a moderate environmental consequence during the operations phase and a moderate negative environmental consequence in the long term. Potential moderate long-term negative impacts, due to the loss of specific existing topographic features, are partially offset by possible positive long term sustainability impacts from a socio-economic perspective. These possible improvements are related to specific kinds of land use that are rated moderate in overall sustainability consequence.

Under the cumulative development case, a project expansion from 100,000 to 400,000 tonnes per year production could considerably increase the extent of impacts on topography and geomorphology, resulting in a high level of environmental consequence for such a development. However, the uncertainty of predictions under the cumulative development case is higher than the uncertainty for the TFM project, making it difficult to assess environmental consequences for the cumulative case.

C2.2 GEOLOGY

No assessment is required for this discipline. This section is included to allow for consistency in section numbering between Volumes B and C.

C2.3 GEOCHEMISTRY

No assessment is required for this discipline. This section is included to allow for consistency in section numbering between Volumes B and C.

C2.4 SOILS

C2.4.1 Introduction

This section presents the environmental assessment for the effects of the proposed Tenke Fungurume Mining (TFM) project on soil resources, according to the project's terms of reference (Section E8). The information presented includes details on:

- The various soil types and distribution within the study areas.
- The capability of soils for agriculture.
- An assessment of soil types for reclamation suitability.
- The potential for soil erosion with mitigation measures presented to minimize erosion effects.
- The volume of soils available for reclamation activities.
- An assessment of constraints or limitations to achieving vegetation restoration based on anticipated soil conditions.
- The effect of the project on soil quantity and capability.
- The effect of the project on unique copper-rich soils.
- An assessment of the potential for long-term sustainable use of soils and possible development options.

This section is organized as follows:

- Section C2.4.2 describes the study areas.
- Section C2.4.3 discusses the approaches and results for the impact and sustainability assessments.
- Section C2.4.4 provides the cumulative effects assessment.
- Section C2.4.5 discusses the conclusions of the assessment.

A glossary of terms and acronyms used in the section is provided at the back of this volume.

C2.4.2 Study Areas

The assessment Regional Study Area (RSA) for soils is a rectangular area approximately 16 by 30 kilometers in size (Figure C1.6-1). The RSA contains the mine Local Study Area (LSA) as well as numerous urban settlements (including Fungurume, Tenke, Mulumbu and Lukotola) and areas projected to be used by the expanded

project. The RSA contains nearly the entire Dipeta catchment and the southern portion of the Mofia catchment, encompassing approximately 49,470 hectares.

The soils assessment LSA follows the terrestrial (including soils, flora, fauna and biodiversity) LSA for the project (Figure B2.4-1). The LSA has a 500-meter buffer zone surrounding all project aspects and alternatives to account for possible impacts that edge effects may have on flora and fauna. The soils LSA encompasses approximately 14,190 hectares.

C2.4.3 Impact Assessment

This section presents the results of the impact assessment on soil resources. Impacts were evaluated for all three mines (Kwatebala, Goma and Fwaulu) as the area of disturbance for each was known at the time of the assessment. An assessment of cumulative effects, which includes the effects of the Fungurume mine, is provided in Section C2.4.4.

C2.4.3.1 Issue Scoping

The anticipated key issues related to soil resources are:

- Mining activities will result in soil removal and disturbance and may cause changes in soil quality/productivity due to disrupted biochemical cycles, loss of soil organic matter, increased soil erosion/sediment delivery, soil compaction, mixing of soil horizons and soil types and soil contamination.
- The project mining activities may result in some loss of unique soils with high levels of exchangeable copper and cobalt and the associated floral community.

Sustainability issues related to soil resources are:

- Development resulting from the TFM project, along with increased population growth, increased agricultural land clearing and food production may intensify the long-term deterioration of soil quality/productivity.

Several issues relating to soils were noted during the public consultation process (Section A6). These include:

- Concerns about loss of agricultural land due to the construction of mine facilities and roadways.

- Concerns about the loss of trees and vegetation in the concession, the impact this may have on soil erosion, and subsequent impacts on damage to or loss of agricultural land.
- Concerns regarding the location of the waste rock facilities and other mine infrastructure, which communities feel should avoid existing agricultural lands.

C2.4.3.2 Key Questions and Indicators

A linkage analysis for potential impacts to soil resources is presented in Figure C2.4-1. The linkage diagram details the potential direct and indirect pathways between the project, soils and other resources. Other resources affected by changes in soil quality productivity include vegetation, surface water quality, groundwater quality, land use and visual aesthetics. Section 2.4.3.4 provides a detailed linkage for changes to soil quality/productivity. Section 2.4.3.5 provides a detailed linkage for the loss of unique soils. Section 2.4.3.6 provides the linkages for sustaining soil productivity/quality.

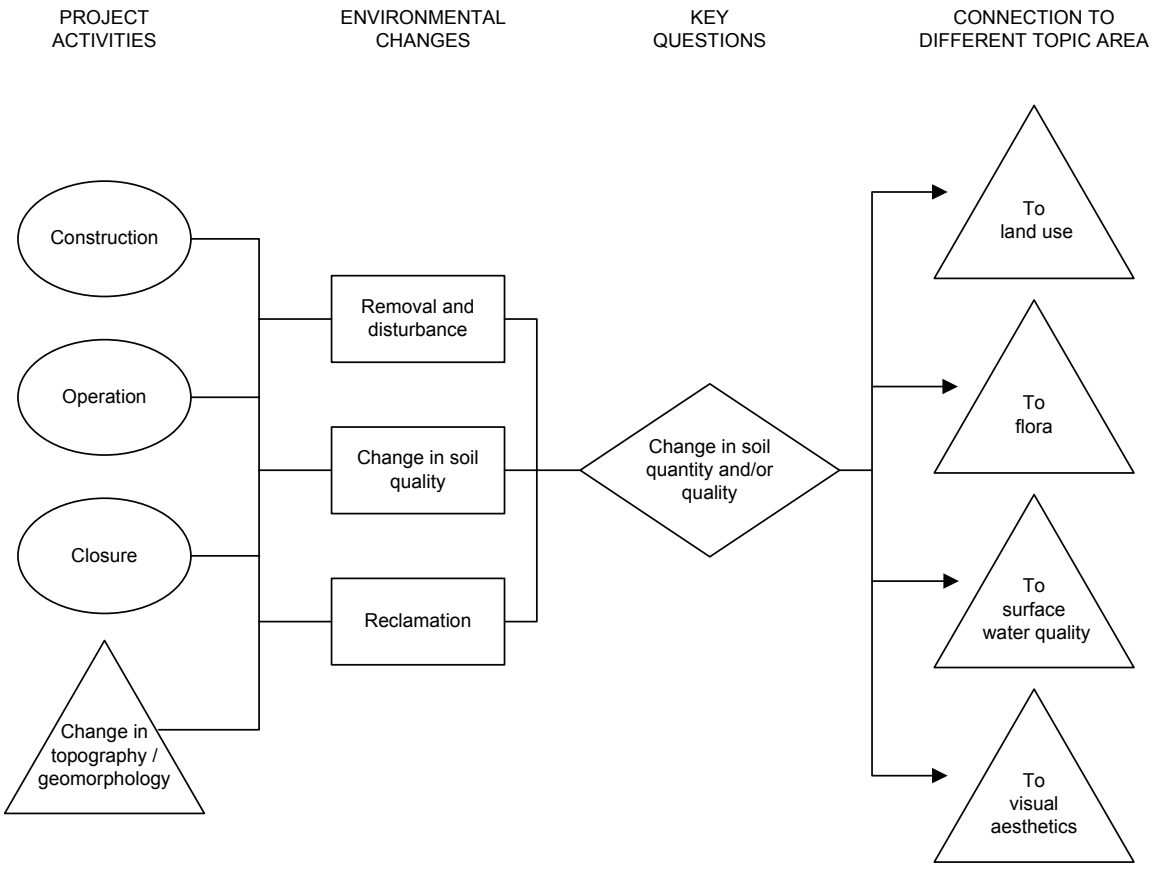
The key questions for soil resources are listed in Table C2.4-1.

Table C2.4-1 Key Questions for Soil Resources

Impact Assessment
SR-1 What effect will the project have on soil quality/productivity?
SR-2 What effect will the project have on loss of unique soils?
Sustainability Assessment
SR-3 How can the project have a long-term positive effect on soil quality/productivity?

Performance monitoring involves periodically measuring the short- and long-term impacts and giving feedback of the results to managers and decision-makers. Performance monitoring is measured using performance indicators. Performance indicators need to be measurable and quantifiable, linked to project activities and meet the specific information needs and scope of authority of the various users. Various users may include field staff, mine managers and decision-makers (World Bank Group 1996). The monitoring and evaluation of project impacts and the success of implemented mitigation measures should be objective and not based on personal judgment or pure description.

Figure C2.4-1 Soil Linkage Analysis



The impacts on soil resources will be measured through a series of performance indicators tailored to site conditions (Table C2.4-2). These indicators will be used for monitoring and evaluating the project impacts and the effectiveness of mitigation measures on soil resources during the life of the project. These key indicators are listed in Table C2.4-2 and are used as part of the soil action plan outlined in Section D3.1.1.

Table C2.4-2 Potential Soil Resource Indicators and TFM Context

GRI Indicator[(a)]		ESIA Indicator	TFM Context
EN 23	for each reporting period, report on land disturbed and rehabilitated	area of land disturbed and reclaimed	TFM is committed to post-mine reclamation and closure. This will be outlined in annual development and reclamation reports showing the land disturbed and rehabilitated. These reports will also provide an indicator of lost soil productivity.
		volume and areas of topsoil/subsoil salvage storage replacement	TFM is committed to the salvage, storage and protection of productive topsoil. This will be outlined in annual development and reclamation reports showing the volume and areas of salvage, storage and replacement.
		crop yields	TFM is committed to reclaim disturbed areas to agriculture or miombo woodland land uses where feasible and in consultation with the surrounding communities. This will be verified by measuring crop yield on reclaimed agricultural land using productivity plots on agricultural and miombo woodland.
		number and effectiveness of erosion control measures	TFM is committed to developing, implementing and monitoring a comprehensive surface water and erosion control plan. The number of erosion control structures and areas revegetated as part of the erosion control plan will be reported annually. Erosion control effectiveness will be monitored by an on-site inspection and reporting program.
		number of reported "spills" and the mitigation measures used to clean up spills	TFM is committed to developing and implementing a spill response plan. Annual operating reports will outline the number of spills, volume of soil contaminated and mitigation measures used to prevent and clean up spills.
		area of unique soils disturbed volume of unique soil salvaged area of unique soils replaced	TFM is committed to reclamation and protection of some of the identified unique copper-cobalt soils and their associated floral communities. This will be outlined in annual development and reclamation reports showing the volume and areas of salvage, storage and replacement of unique soils.

(a) Global Reporting Initiative (GRI 2005b).

C2.4.3.3 Assessment Criteria

The soil impact criteria used to assess impacts on resources resulting from TFM mining activities are presented in Table C2.4-3. The screening system for sustainability consequence is provided in Section A5.

Table C2.4-3 Impact Description Criteria for Soil Resources

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 (less than 1 percent) on the measured endpoint **low:** less than 10 percent change in the measured endpoint **moderate:** 10 to 20 percent change in the measurable endpoint **high:** more than 20 percent change in the measured endpoint	**local:** effect restricted to the Local Study Area (LSA) **regional** effect extends beyond the LSA into the Regional Study Area (RSA) **beyond regional:** effect extends beyond the RSA	**short-term:** less than 3 years **medium-term:** 3 to 20 years **long-term:** more than 20 years	**reversible** or **irreversible**	**low:** occurs once or rarely **medium:** occurs intermittently **high:** occurs continuously

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

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

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

(d) Duration: length of time over which the environmental effects occurs. Considers a two-year construction period and a 20-year operation period.

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

(f) Frequency: how often the impact occurs.

C2.4.3.4 Key Question SR-1

Key question SR-1 is: What effect will the project have on soil quality/productivity?

Issues that are related to soil quality/productivity during the construction, operation and closure phases of the project include:

- Soil removal and disturbance.
- Loss of soil organic matter/changes in biochemical cycle.
- Soil erosion/sediment delivery.
- Sedimentation.
- Soil compaction/change in soil structure.
- Mixing of topsoil and subsoil.
- Mixing of different soil types.
- Soil contamination.
- Reclamation.

These identified issues are discussed below.

Linkage Evaluation

Figure C2.4-1 provides a linkage evaluation of the project phases and soil quality/productivity linkages. During the construction phase, activities such as site clearing, topsoil salvage and storage, subsurface stripping and construction of processing facilities, roads and tailings dams can affect soil quality/productivity. During the operations phase, activities such as mining, waste rock disposal, tailings production and leaks and spills can affect soil quality/productivity. During the closure phase activities such as site preparation, soil replacement and revegetation can affect soil quality/productivity.

Soil Removal and Disturbance

The main disturbances from the TFM project will be plant construction, tailings storage facility construction and open pit mining. The mining process results in the physical removal of the entire soil profile. Soil removal and disturbance can also affect vegetation, land use and visual aesthetics (Figure C2.4-1). This is a valid linkage.

Loss of Organic Matter/Changes in Biochemical Cycle

Soil organic matter content affects soil fertility, soil aggregate stability, soil infiltration, resistance to crusting and soil structure. The sustainability of soil nutrient supply in disturbed tropical soils has been identified as a potential issue. Organic matter content is a key soil characteristic that determines many factors of the sustainability of tropical soil fertility (Young 1976).

Soil organic matter develops over time, under equilibrium conditions, where the rate of input from decomposing plant material approximately equals plant uptake (Hausenbuiller 1972). Changes in soil organic matter content will affect both soil carbon and nitrogen content. Organic nitrogen is the dominant form of soil nitrogen in tropical soils (Young 1995). This form of nitrogen in most tropical forest soils is not available after a long period of cultivation and, by extension, after severe disturbances such as mining.

Tropical and subtropical soils are often very low in nutrients, have a low pH, low phosphorus availability and possible aluminum toxicity as outlined below:

- Tropical soils have low cation exchange capacities indicating that the soil is highly limited in retaining nutrients, are easily disrupted by agricultural practices and exhibit a tendency to inactivate available phosphorus (Young 1976).
- pH is a useful indicator of chemical fertility. The pH affects solubility of minerals and the activity of soil microbes to convert organic minerals to

soluble inorganic forms (plant nutrients). Slightly acidic soils to neutral soils with pH values of 5.3 to 7.0 are favorable for cultivation and nutrient release.

- Phosphorus (P) is one of the most deficient plant nutrients in weathered tropical soils. Phosphorus deficiency is widespread in the tropics, due to either phosphorus fixation or low total phosphorus reserves in organic matter and strong weathering (Juo and Franzluebbers 2003). Tropical soils contain high iron and aluminum oxides that react with soluble phosphate ions released during mineralization to form less soluble iron and aluminum phosphates. This process is known as phosphorus fixation. Much of the phosphorus content and other cations are derived from the organic fraction.
- Strongly acidic soils (pH < 5.2) are widely encountered in the humid tropics. These soils can also lead to mineral deficiencies (Juo and Franzluebbers 2003).
- The amount of aluminum (Al) and manganese (Mn) present in the soil solution may become toxic to various crops. High concentrations of aluminum affect root growth, uptake, translocation of nutrients and immobilization of phosphorus.

Maintaining the topsoil in tropical and subtropical soil is necessary to offset some of the limitations caused by low cation exchange capacity, low acidity, low phosphorus availability and possible aluminum toxicity.

The TFM project has the potential to cause a net loss of soil organic matter during salvage operations or when soil is stockpiled. Decomposition and mineralization of soil organic matter can occur when soil is stockpiled over a long period. A net loss in soil organic matter results in lower soil fertility and a loss of soil structure and tilth (suitability for agricultural purposes). Loss of soil organic matter leads to changes in the biochemical cycle. Both can effect vegetation and land use. This is a valid linkage.

Soil Erosion/Sedimentation

Soil erosion is the displacement of soil by wind or water. According to Wischmeier and Smith (1961) the following features can effect soil erosion:

- Rainfall.
- Soil credibility.
- Slope length.
- Slope gradient.
- Vegetative cover.
- Erosion control practices.

Soil erosion risk is related to soil erodibility and erosivity. Soil erodibility is the susceptibility of a soil to erosion. Erosivity is the capacity of water to erode soils.

Soil erodibility is affected by soil organic matter, soil texture and soil structure. Generally soils high in silt and very fine sand are more susceptible to erosion than other soils. Soil with higher levels of organic matter and well-developed aggregate structure are less susceptible (prone) to erosion. The amount of soil vegetative cover is an important factor in erosion control, especially in high rainfall areas. Soil water erosion is greater where the raindrops reach the ground with high kinetic energy (i.e., not intercepted by vegetation).

Sediment delivery is the movement of displaced soil particles (sediment) off site into an ephemeral, intermittent or perennial watercourse.

The TFM project has the potential to increase soil erosion and/or sediment delivery through removal of vegetation, changing soil structure and organic matter and entraining (transporting) the sediment in runoff from the cleared areas. Soil erosion/sediment delivery needs to be minimized on areas stripped of vegetative cover prior to mining activities, during mining operation and on the post-mining landscape. Soil erosion/sediment delivery can affect surface water quality, land use and visual aesthetics. This is a valid linkage.

Soil Compaction/Change in Soil Structure

Soil compaction results in reduced soil pore space (the spaces between soil particles). Soil compaction occurs when force compresses the larger soil pores and reduces the air volume of the soil. Compacted soils have higher bulk densities than non-compacted soils. Soil compaction results in:

- Decreased movement of water and air into and within the soil profile (Gupta and Allmaras 1989).
- Decreased available soil water storage for plant use.
- Decreased water infiltration and increased surface runoff and erosion.
- Soil compaction can also modify soil hydrology, groundwater recharge and increase the risk of runoff and water erosion.
- Reduced plant root growth and penetration (Wolf and Hadas 1984).
- Decreased plant root penetration into the soil profile with resulting decrease in availability of soil water and nutrients to plants.

The potential of a soil to compaction depends on the soil's physical properties (such as texture and water content) and the amount and nature of the force

applied. Soil compaction is a potential issue whenever vehicular traffic passes over soil intended to support plant growth. Soil compaction is most severe under moist conditions, high loads and areas of repeated traffic use. Soil compaction issues can take years to remedy or improve.

Alteration of soil structure can result from a reduction in soil porosity, an increase in soil density and a loss of soil aggregates. Alteration of soil structure can impact vegetation growth, especially root development.

The TFM project has the potential to cause both soil compaction and an alteration of soil structure. Soil salvage operations will involve equipment traffic and activity on soils that could result in soil compaction and alteration of soil structure. Repeated vehicular traffic in the plant and mine area over the life of the project could also result in soil compaction. Soil compaction or change in soil structure can impact vegetation and land use. This is a valid linkage.

Mixing of Soil Horizons

The organic matter horizon of tropical soils contains the majority of soil nutrients (Young 1976). Care should be taken to ensure that this horizon is preserved during project construction for later use in reclamation. The availability of plant nutrients, such as phosphorus, can diminish in soils due to depletion of plant litter caused by clearing and other processes such as leaching, oxidation and mineralization.

The TFM project has the potential to mix soil horizons by overstripping or understripping during reclamation material salvage and replacement operations. Overstripping or understripping may be caused by equipment operator error, equipment limitations or variability in soil horizon depths. Mixing of soil horizons can also result in reduced or altered post-mine land capability. This, in turn, can impact vegetation and land use. Mixing of soil horizons is a valid linkage.

Mixing of Soil Types

Within the project LSA there are two distinct soil types:

- Soils high in exchangeable copper-cobalt on mineralized outcrops.
- Soils low in exchangeable copper-cobalt on agricultural land and miombo woodland.

Mixing of these two soil types during salvage and reclamation activities could result in soils with phytotoxic levels of copper and cobalt in areas designated for agricultural crops or low levels of copper and cobalt in areas reclaimed to copper-cobalt vegetation.

The project has the potential to mix soil types through operator error or the inadvertent mixing of soil types during salvage operations. Mixing the soil types can also result in reduced or altered post-mine land capability which, in turn, can impact vegetation and land use. This is a valid linkage.

Soil Contamination

The chemistry of soils and their capability can be altered by leaks, seepage, and spills of substances from industrial sources.

The TFM project has the potential to cause soil contamination resulting from spills and leaks during construction and operation phases. Soil contamination can result in the alteration of soil chemistry and physical properties. Soil contamination can impact vegetation, surface water and groundwater quality. This is a valid linkage.

Reclamation

Land reclamation is the reconditioning of the land to a state suitable for some future use. Land reclamation includes the stabilization, contouring, maintenance, conditioning, reconstruction and revegetation of the land surface. Alberta Environment (2006) describes land reclamation efforts as the removal of equipment, buildings or other facilities, the decontamination of the site and the stabilization, contouring, maintenance, conditioning or reconstruction of the surface of land. Often the goal of reclamation is returning the land to equivalent land capability so that it is able to support land uses similar to those that existed prior to disturbance. Reclamation affects land use, vegetation, surface water quality, groundwater quality and visual aesthetics. This is a valid linkage.

Assessment Methods

A reconnaissance-level baseline soil map was produced based on field studies and remote sensing imagery data (Section B2.4). The baseline soil map outlined nine soil map units. The proposed mine development footprint was superimposed on (laid over) the baseline soils map. The areas of each soil unit disturbed were calculated and compared to the baseline areas of each soil type.

Mitigation

The following mitigation measures for each valid linkage will be used to minimize impacts on soil quality/productivity:

Soil Removal and Disturbance

Soil removal and disturbance will be an issue during construction and operation phases. Mitigation measures will include the following methods:

- Progressive reclamation will take place, where possible, to minimize the mine footprint.

Loss of Organic Matter/Loss of Biochemical Cycle

Soil productivity and the loss of the soil biochemical cycle will be an issue during the construction, operation and closure phases. Mitigation measures will include the following methods:

- Selective salvage and storage of topsoil layers.
- Minimizing the length of time topsoil will be stockpiled.
- Replacement of a reconstituted soil profile, as much as feasible, with soils from the salvage program.
- Incorporation of organic matter in the topsoil along with direct topsoil salvage and replacement, placement of composted organic material, mulching and "green manuring".
- Nutrients deficient to plant growth could be added to the soil, with fertilizer amendment.

Soil Erosion/Sediment Delivery

Soil erosion/sedimentation during the construction and operation phases will be mitigated using the following methods:

- Minimize denuded area at any given time by practicing progressive vegetative clearing just prior to construction and mining activities.
- Promptly revegetate exposed areas and topsoil stockpiles to control erosion.
- Locate salvaged topsoil storage piles away from areas of high erosion potential.
- Use physical erosion control measures such as silt fences, interceptor ditches and berms, rock check dams, sediment ponds, mulches, tackifers, mats or netting to control erosion prior to the establishment of a protective vegetative cover.

- Construct roads and landscape features so natural drainage patterns are not impeded and that runoff to road ditches enters natural drainage systems or contoured containment areas.
- Establish a monitoring plan for identifying potential erosion problems early and implement mitigation measures where necessary.
- Establish a sustainable self-sufficient vegetative community on the post-mine project landscape.

Additional erosion control techniques are provided in the soil action plan (Section D3.1.1).

Soil Compaction

Soil compaction will be an issue during the construction and operation phases of the TFM project. Soil compaction will be mitigated using the following methods:

- Minimize vehicular traffic, where possible, during soil salvage, soil replacement and reclamation operations.
- Avoid soil salvage, soil replacement and reclamation operations during wet weather, unless sediment runoff controls are in place.
- Chisel or deep plow reclaimed soil with suspected compaction problems before topsoil replacement and revegetation.
- Where required, mulch and incorporate organic matter, such as straw or wood waste, into the surface layers of reclaimed soils.
- Revegetate with deeper-rooting grasses, trees and shrubs to loosen compaction.

Mixing of Soil Horizons

The mixing of soil horizons will be an issue during the construction, operation and closure phases of the project in areas where both the topsoil and subsoil are salvaged and replaced. Mitigation will use the following methods:

- Selective soil salvage and storage of soil horizons.
- Any salvage subsoil should be segregated from topsoils.
- Selectively replace subsoil and topsoil horizons.

Mixing of Soil Types

The mixing of agricultural/miombo woodland and copper-cobalt soil types will be an issue during the construction, operation and closure phases. Soil mixing will be mitigated using the following methods:

- Plan separate soil salvage and placement operations for the copper-rich and barren (i.e., normal) soil types.
- Designate separate storage locations for copper-rich and non-copper-rich soils.

Soil Contamination

Soil contamination will be an issue during the construction and operation phases. Soil contamination will be mitigated using the following methods:

- Develop a comprehensive spill response and clean-up plan.
- Designate fuel and chemical storage, fueling and use areas.
- Design project facilities with secondary containment systems that minimize contaminant spills.

Progressive Rehabilitation

Progressive rehabilitation will be conducted during the operations phase and will run concurrently with the mining and processing operations where possible. The progressive rehabilitation program will only pertain to portions of the tailings storage facility dam walls. Transmission line and road right-of-ways and other areas that will not be used later will be rehabilitated after construction, as will any areas no longer in use (e.g., abandoned roads). The details of the rehabilitation measures to be implemented for the whole project at closure are described in detail in the reclamation and closure plan (Section D5).

Results

A total of 2,397 hectares (16 percent of the LSA) of soil will be disturbed during the operation phase by the mine, tailings storage facility, processing plant site, roads, low-grade ore stockpiles, waste rock facilities and soil storage piles over the life of the project (Table C2.4-4). The most disturbance will occur in soil map unit 2 (1,414 hectares, 9.5 percent of the LSA) and soil map unit 3 (378 hectares, 2.5 percent of the LSA). Soils in these two units are mainly Oxisols with organically enriched A horizons.

Table C2.4-4 Disturbance of Soil Map Units in the Local Study Area

Soil Map Unit	Baseline Area (ha)	Percentage of LSA	Loss from Project Development during Operations (ha)	Percent of Individual Soil Unit Disturbed during Operations	Percent of LSA Disturbed during Operations	Area of Disturbed Soil Fully Reclaimed after Closure (ha)[a]	Area of Disturbed Soil Partially Reclaimed after Closure (ha)[b]	Loss from Project Development after Closure [c]	Percent of Individual Soil Unit Disturbed Lost after Closure	Percent of LSA Disturbed after Closure
1	2,148	14	396	18	2.7	0	273	396	18	3
2	7,858	53	1,414	18	9.5	222	595	1192	15	8
3	3,641	25	378	10	2.5	49	112	329	9	2
4	477	3	33	7	0.2	10	21	23	5	0.2
5	221	1.5	16	7	0.1	<0.1	16	16	7	0.1
6	131	0.9	121	92	0.8	0	0.5	121	92	0.8
7	295	2	20	7	0.1	14	4	6	2	<0.1
8	8	0.1	3	38	<0.1	3	0	0	0	<0.1
9	36	0.2	15	44	0.1	2	0	13	38	0.1
Total	**14,816**	**100**	**2,397**		**16**	**300**	**1,022**	**2,096 [d]**		**12.2**

[a] An area fully reclaimed will have one meter of subsoil and a topsoil layer replacement and should support land uses (agriculture and miombo woodland) at a similar capability to that that existed prior to disturbance.

[b] An area partially reclaimed will have a layer of topsoil replacement and will support a self sustaining plant community.

[c] The loss after closure is the area disturbed during operations minus the land that is fully reclaimed.

[d] Total adds precisely to 2,097, but is 2,096 due to rounding of above numbers to whole numbers. Thus, 2,397 = 300 + 2,097. Of this 2,097, 1,022 is partially reclaimed and a total of 1,075 ha will not be reclaimed at all.

Notes: Due to rounding conventions, numbers may not equal totals.

ha = hectare.

After reclamation and closure about 300 hectares will be fully reclaimed. It is assumed that the processing plant topsoil piles will be returned to agriculture or miombo woodland that is able to support land uses similar to those that existed before disturbance. This will leave 2,097 hectares un-reclaimed after closure. However, approximately 1,022 hectares of this 2,097 hectares will be partially reclaimed with a topsoil layer that should support a self sustaining plant community. This includes the following areas and disturbances:

- **Tailings storage facility and waste rock facilities –** A topsoil layer will be placed over large portions of these facilities. Please see Section D5, Reclamation and Closure Plan, for details on where topsoil will be used. A rock cover will be used on portions of the facilities. Low-grade ore stockpiles are planned to be processed and will not be revegetated unless they are left in place at closure. A topsoil layer will be placed over areas that were occupied by low grade ore stockpiles after these stockpiles are processed. All topsoiled areas will be revegetated with a self sustaining plant community.
- **Roads** – The roads will be recontoured and revegetated unless communities want the facilities to remain open and maintained.
- **Water reservoir** – The water reservoir will remain and will not be returned to terrestrial vegetation.
- **Mine pits** – Mine pits will be closed so that public safety is not at risk. No topsoil will be used to reclaim the open pits.

The majority of the residual disturbance and partially reclaimed area occurs in soil map unit 2 (1,192 hectares, 8 percent of the LSA), soil map unit 1 (396 hectares, three percent of LSA) and soil map unit 3 (329 hectares, two percent of the LSA) (Table C2.4-4).

Impact Analysis

The residual impact classification of the TFM project on soil productivity/quality during the operation phase is negative in direction, moderate in magnitude, local in geographic extent, long term in duration, reversible, high frequency and has a moderate environmental consequence (Table C2.4-5). Successful reclamation will significantly lower the environmental consequence. The residual impact classification of the TFM project on soil productivity/quality following closure is negative in direction, moderate in magnitude (following soil salvage and reclamation), local in geographic extent, long term in duration, reversible, high frequency and has a moderate environmental consequence (Table C2.4-5).

Table C2.4-5 Residual Impact Classification for Key Question SR-1

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question SR-1: What effect will the project have on soil quality/productivity?						
Operation Phase						
negative	moderate	local	long-term	reversible	high	moderate
Closure Phase						
negative	moderate	local	long-term	reversible	high	moderate

Prediction Confidence

The soil impact classification and soil map unit types rely on several sources of information. The project description and soil information is provided from a reconnaissance-level soil map. In addition, this assessment relies heavily on the planned soil salvage, storage and reclamation plans to return the disturbed areas to pre-disturbance conditions. There could be inaccuracies in the reconnaissance-level soil map, especially for detailed site-specific information. There are some uncertainties regarding the effectiveness of soil salvage and some uncertainties about the reclamation of tropical soils. Overall, the prediction confidence for the impacts to soil quality/productivity is moderate.

Monitoring

The impact of TFM mining activities on soil quality/productivity will be monitored by the following methods:

- Annual reporting on the soil salvage and reclamation activities including area disturbed, area and volume of soil salvaged, area recontoured, area of soil replacement, area of reclaimed land treated with amendments such as ripping, mulching and/or fertilizers and area reclaimed to designated land use.
- Annual monitoring on the effectiveness of erosion control efforts including erosion control structures and measures implemented.
- On-site reports of noticeable erosion issues, including sediment delivery to watercourses.
- Annual reporting on the effectiveness of the spill response plan, including a summary of significant spill incidents and mitigation measures. On-site spill incidence response reports will be completed as required.
- Establishment of reclamation success monitoring plots to determine the effectiveness of reclamation activities. Monitoring criteria will be established based on reference areas and the post-mining land use being

re-established. Productivity monitoring will be performed on areas where the post-mining land use is agricultural.

Indicators for the monitoring program are provided in Table C2.4-2. A full monitoring program is provided in the soil action plan in Section D3.1.1.

C2.4.3.5 Key Question SR-2

Key question SR-2 is: What effect will the project have on loss of unique soils?

Unique soils in the context of the project are the copper-cobalt soils of map unit 6. The key question includes all issues relative to the loss of this unique soil during the construction, operation and closure phases of the project. The loss of unique soils with high levels of exchangeable copper and cobalt and their associated flora community has been identified as a potential issue of concern in the project area. Specific issues related to this key question include:

- Soil removal and disturbance.
- Reclamation.

Linkage Evaluation

Soil Removal and Disturbance

The TFM project will result in the complete removal of soil high in exchangeable copper-cobalt located on the ore bodies that will be mined. These soils support a unique floral community. The loss of these soils will effect this vegetation (Figure C2.4-1). This is a valid linkage.

Reclamation

Reclamation of unique soils will need to occur if a portion of the land can support the unique floral communities that existed before mining disturbance. Unique soil reclamation affects land use, vegetation and visual aesthetics (Figure C2.4-1). This is a valid linkage.

Assessment Methods

A reconnaissance-level baseline soil map was produced based on field data and remote sensing imagery data. The map outlines areas of copper-cobalt soils. The proposed mine development footprint was superimposed on the soils map. The areas of copper-cobalt soils potentially to be disturbed by mining activities were calculated and compared to baseline areas of this soil type.

Mitigation

The loss of unique copper-cobalt rich soils will be an issue during the construction and operation phases. The loss of these soils will be minimized by the following methods:

- Salvage some copper-rich soils and the host rocky substrate, and store them in a separate area and use for reclamation of copper-cobalt flora by replacing soil in designated areas.
- Direct salvage and replacement of copper-rich soil and rocky substrate to identified off-site areas, where feasible.

Results

Unique copper-cobalt soils occupy a small percentage of the LSA (131 hectares, 1.0 percent of the LSA). Approximately 121 hectares of these unique soils will be disturbed by mining activities (Table C2.4-6).

Table C2.4-6 Disturbance of Unique Soil Map Units in the Local Study Area

Soil Map Unit	Baseline Area (ha)	Percentage of LSA	Loss from Project Development during Operations (ha)	Percent of Individual Soil Unit Disturbed during Operations	Percent of LSA Disturbed during Operations	Loss from Project Development after Closure (ha)	Percent of Individual Soil Unit Disturbed after Closure	Percent of LSA Disturbed after Closure
6	131	0.9	121	92.6	0.8	121	92.6	0.8

ha = hectare.

Impact Analysis

The residual impact classification of the TFM project on loss of unique soils in both the operation and closure phases is negative in direction, high in magnitude, local in geographic extent, long term in duration, reversible, high frequency and has a high environmental consequence (Table C2.4-7). The reversibility of impacts is assumed here because, during the operations phase, there is an opportunity to reverse some of the mine disturbance through reclamation. A high

environmental consequence for copper-cobalt soils is not unexpected given that these soils occur on the target ore bodies. The reclamation of about 13 hectares of these soils is not sufficient to change the closure phase ranking. These copper-cobalt soils in and of themselves are not a highly valued resource, but the copper-cobalt flora supported by these soils is very highly valued. Effects on this flora is evaluated in Section C3.1.

Table C2.4-7 Residual Impact Classification for Key Question SR-2

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question SR-2: What effect will the project have on loss of unique soils?						
Operation Phase						
negative	high	local	long-term	reversible	high	high
Closure Phase						
negative	high	local	long-term	reversible	high	high

Prediction Confidence

The impact classification for loss of unique soils relies on reconnaissance-level 1:20,000 soil map and limited field surveys. There could be inaccuracies in the 1:20,000 soil map in identifying all the copper-cobalt soils in the LSA since there was not a comprehensive inspection of other possible outcrops where copper-cobalt soils may exist. There are also some unknowns regarding the ability to operationally salvage and replace thin layers of copper-cobalt rich soils. Overall, the prediction confidence for the TFM project on loss of unique soils is moderate.

Monitoring

The impact of the TFM mining activities on unique soils will be monitored by:

- Annual reporting on areas of unique soils disturbed and volume of unique soils salvaged, stored and replaced on the post-mine landscape.

C2.4.3.6 Key Question SR-3

Key question SR-3 is: How can the project have a long-term positive effect on soil quality/productivity?

The development of the project will have both direct and indirect effects on soil productivity/quality (see Section C2.4.3.4 and Section C2.4.3.5). The direct effects of the mine on soil quality/productivity are outlined in the previous two sections. The

indirect effects of the TFM project may include more people moving into the area looking for employment and economic opportunities. Associated with this population increase may be more land clearing and cultivation activities. There will be a greater demand for food from the increased population and many of the migrants who move into the area may engage in land clearing and cultivation activities for subsistence.

Linkage Evaluation

The effects of the increasing population, such as increased land clearing and cultivation activities on soil quality/productivity and agricultural capability, are outlined in Figure C2.4-2. Figure C2.4-2 also outlines the mitigation measures that can be used to sustain soil quality/productivity and agricultural capability.

Increased land clearing and farming activities will have the following effects on soil quality/productivity:

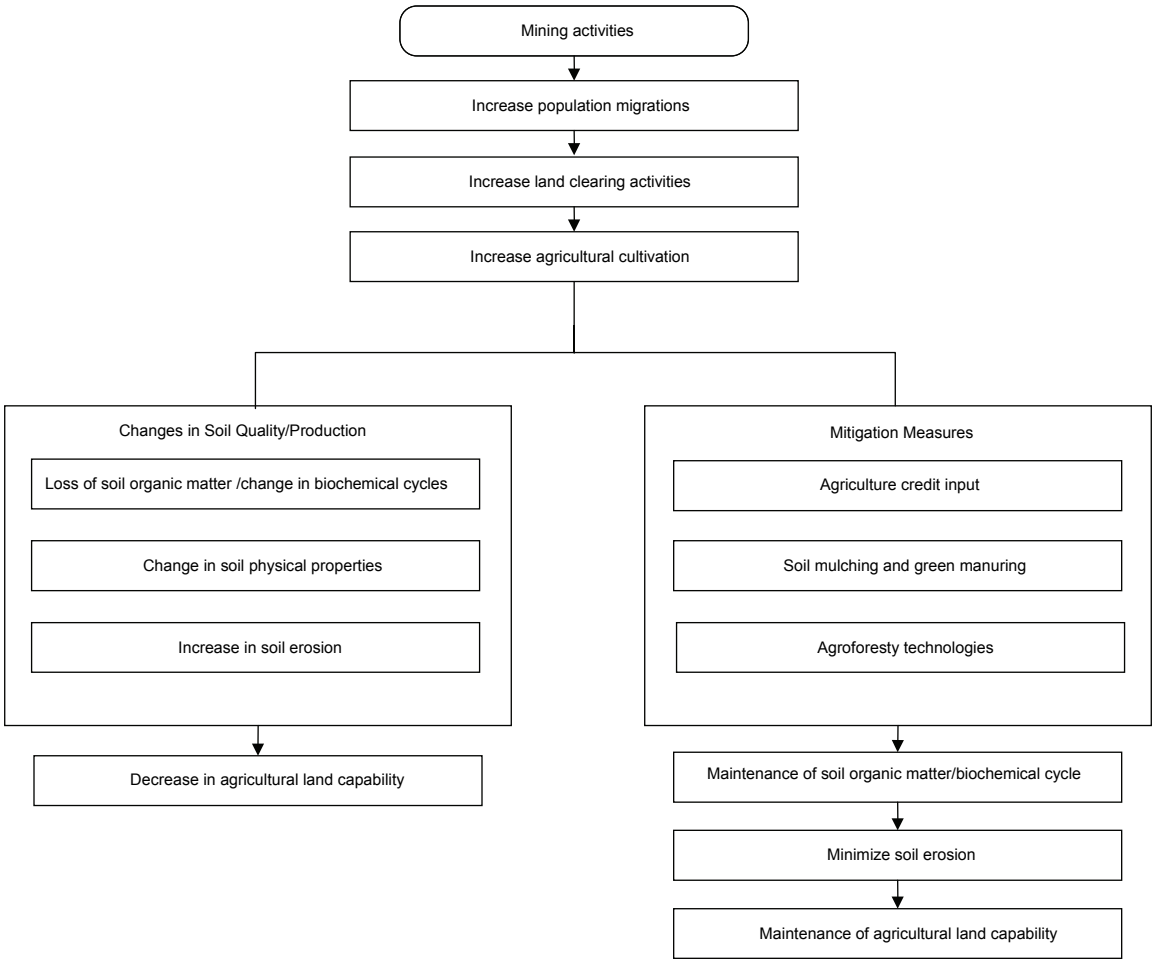
- Loss of soil organic matter/changes in biochemical cycle.
- Change in soil physical properties.
- Increase in soil erosion.

Each of these effects is discussed below.

Loss of Soil Organic Matter/Change in Biochemical Cycle

Continuous cultivation can lead to changes in soil organic matter/biochemical cycles and declining yields of agricultural crops. Organic matter contents can drop dramatically if land is continuously cultivated and not left fallow (uncultivated). This can cause deterioration of the nutrient status of the soil, topsoil erosion, deterioration of the soil's physical properties, multiplication of pests and diseases and an increase in weeds (Nye and Greenland 1960). An increase in population may also increase the pressure on the land by lengthening the cropping (growing) periods and shortening fallow periods. The accompanying loss of soil organic matter and plant nutrients can lead to a long-term decline in soil quality/productivity.

Figure C2.4-2 Linkage Diagram for Indirect Effects to Soil Resources



Change in Soil Physical Properties

Increased cultivation and the accompanying long-term loss of soil organic matter can also affect soil properties such as aggregate stability and infiltration capacity. The soil's physical properties will change when the fertility (nutrients) has been depleted by too much cropping. This will lead to a long-term decline in soil quality/productivity.

Increase in Soil Erosion

Increased land clearing and cultivation will reduce vegetative cover, alter some soil characteristics and increase the risk of accelerated soil erosion. The adverse effects of soil erosion include a loss of soil, a reduction in crop yields and a long-term decline in soil quality/productivity.

Assessment Methods

In general, assessment methods relied on professional experience in relation to the changes in soil quality/productivity due to increased land clearing and cultivation.

Mitigation

The efforts required for minimizing disturbance of soil resources during construction and operation are generally within the control of the project. The efforts required for minimizing the deterioration of soil resources that may indirectly result from mining development are somewhat beyond the control of the project. TFM does not have the responsibility, authority or the capacity to completely mitigate changes in soil quality/productivity or long-term consequences to agricultural capability resulting from increasing population and changing land use patterns. Mitigation measures required to sustain soil resource quality/productivity will require long-term efforts that involve active community participation and input.

Loss of soil organic matter, change in soil physical properties, soil erosion and subsequent decline in soil quality/productivity and agricultural capability may be potentially minimized through mitigation measures such as agricultural credit, agroforestry, green manuring and soil mulching. A brief description of these mitigation measures are outlined below.

It is important to note that the major constraints in implementing these mitigation measures are social and economic, not technical. Community involvement and

participation are essential to the success of the proposed mitigation measures. The assumption that individuals or communities will be able to easily move from present practices to more intensive practices with unfamiliar technologies and inputs is unrealistic. The poor economic and social situation people face means they are often unwilling to risk trying new methods or technologies. Successful adoption of new practices is often dependent on a well-organized agricultural education (extension) effort, strong local leadership and community cohesion. In addition, the efforts need to build on local knowledge and capacity and may not be exactly replicated from one area or community to another.

All the proposed mitigation measures, such as adoption of agroforestry or mulching technologies, will require a well-organized and motivated extension team. This extension team, if in place, could also provide advice or input on implementing mitigation efforts for other disciplines.

Agricultural Credit

Improved access to agricultural credit for crops, purchase of farm inputs, crop storage, animal husbandry or small business or enterprise expansion will have many beneficial effects. These effects will include maintenance of soil quality/productivity and agricultural capability since it will offer the opportunities for farmers to purchase inputs such as fertilizer or adopt new farming technologies. The provision of agricultural credit is complex and needs to fit local conditions and be flexible. The details of any agricultural credit program, whether in the form of a rotating credit fund, loans to individuals, loans to groups or credit cooperatives, will need to be determined at a later date. TFM is not in the business of providing agricultural credit but may consider providing "seed" money to start-up an agricultural credit program. Agricultural credit for fertilizer is known in the concession area, and most villagers are interested (George Koppert, pers.comm.). Innovative credit mechanisms, such as barter of fertilizers for future crop production, may be appropriate.

Agroforestry Systems

Agroforestry is a collective name for land use systems where woody perennials are deliberately used either spatially (space-based) or temporally (time-based) on the same field as agricultural crops or animals. Social forestry is the practice of using trees and/or tree planting to pursue social objectives, such as economic development, through the delivery of benefits to local people. Community forestry, a form of social forestry, refers to activities taken by a community on communal lands. Community forestry is based on people's participation in the process. These systems should have the following characteristics (Nair 1993):

- **Productivity** – maintain or increase production of preferred commodities as well as the productivity of land. This could include increased output of tree products, improved yield crops, reduction in cropping system inputs and/or increased labor efficiency.
- **Sustainability** – conserving the production potential or the resource base through the beneficial effects of soil agroforestry to achieve and indefinitely maintain conservation and fertility goals.
- **Adoptability** – any introduced new or improved agroforestry systems or technologies need to conform to local farming system practices so that they are more easily adopted.

Agroforestry systems can range from low-input swidden (slash and burn) agricultural systems that are presently practiced in the LSA, to more complex and labor-intensive alley cropping (hedgerow intercropping where perennial trees or shrubs are grown with arable crops) (Young 1994; Hudson 1995). An appropriate agroforestry system is very closely linked to its economic feasibility and must also respond to socio-cultural factors. Improved agroforestry systems hold promise for maintaining or improving soil fertility and reducing erosion. The agroforestry system best-suited for the project area needs to be explored in more detail.

Soil Mulching

Soil mulching is the layering of plant residue on the soil surface underneath the crop. Soil mulch reduces soil water erosion, raises the organic carbon content of the topsoil, promotes the formation of water-stable aggregates, enhances soil structure, moderates soil temperature and increases organic matter status. Mulch can also aid in reducing weed growth and which may result in reducing labor inputs. Mulching's effect on reducing soil water erosion is caused by minimizing the impact of raindrops hitting the soil surface, reducing the runoff velocity and allowing for more water infiltration (Hudson 1995).

Some mulching is practiced in the area, but mulching does not appear to be practiced extensively. Widespread implementation of mulching as an agricultural practice would require a large participatory extension campaign. The feasibility and implementation of mulching as an agricultural practice needs to be explored in more detail. Mulching offers promise as a soil conservation technology for maintaining soil fertility and reducing soil erosion.

Green Manuring

Green manuring is the practice of turning undecomposed green plant tissue into the soil. The function of a green manure crop is to add organic matter to the soil in order to increase soil fertility, improve soil structure and reduce erosion. Specific crops, such as those that bind nitrogen, could be grown for the purpose of green manuring.

Green manuring also offers promise as a soil conservation technology for maintaining soil fertility and reducing erosion. Green manuring adoption by local farmers will require the provision of appropriate farm equipment, such as plows or hoes for incorporating plant tissues into the soil. A collaborative extension effort with farmers will also be required. The feasibility and implementation of improved green manuring technologies needs to be explored in more detail.

Results

It is anticipated that long-term soil quality and productivity can be sustained by implementing mitigation measures such as agricultural credit, agroforestry, soil mulching and green manuring.

Impact Analysis

The residual impact classification of sustaining soil quality/productivity based on proposed mitigation measures is high to moderate in magnitude, reaches half the community, has a medium probability of success and a medium sustainability consequence (Table C2.4-8).

Table C2.4-8 Residual Impact Classification for Key Question SR-3

Magnitude	Span or Reach	Duration	Probability of Success	Final Sustainability Consequence
Key question SR-3: How can the project have a long-term positive effect on soil quality/productivity?				
Agricultural Credit				
high	half the community	long-term	medium	moderate
Agroforestry				
moderate	half the community	long-term	medium	moderate
Soil Mulching				
moderate	half the community	long-term	medium	moderate
Green Manuring				
moderate	half the community	long-term	medium	moderate

Prediction Confidence

The impact analysis is based on incomplete knowledge of the span or reach or the probability of success of the proposed mitigation measures. The number of people who would be interested or able to participate in the proposed mitigation measures, the exact nature of the mitigation measures and the training and extension efforts required is not precisely known. Overall, the prediction confidence of sustaining long-term soil quality/productivity is high. Agricultural programs, if correctly managed, can be very successful in rural Africa.

Monitoring

A detailed monitoring and evaluation program will need to be developed once the exact nature and feasibility of the mitigation measures are known. The monitoring program will need to assess both the implementation effectiveness of the proposed mitigation measures and the effectiveness of the efforts in maintaining soil quality/productivity. Some of the criteria for consideration include:

- Number of individuals or communities participating in agricultural credit, agroforestry, mulching or green manuring programs.
- The pay-back rate on any agricultural credit loans facilitated by TFM community development actions.
- Number of extension visits to individuals or communities.
- Number of individuals or communities adopting new agroforestry, green manuring or soil mulching technologies.

- The agricultural yields on lands where agroforestry, soil mulching or green manuring practices were implemented.

A more detailed discussion of soil monitoring is outlined in Section D3.1.1.

C2.4.4 Cumulative Effects Assessment

There are currently no other planned mining developments in the LSA or RSA. There is a possibility that mine production for the TFM project may expand from 115,000 tonnes of copper production per year to 400,000 tonnes per year (Section A4.17).

Linkage Evaluation

An expansion from 115,000 tonnes of copper production per year to 400,000 tonnes per year would significantly increase the disturbance footprint. Additional areas would need to be mined and additional areas would be required for tailings storage facilities.

Assessment Methods

Detailed plans for the additional development of the project to expand to 400,000 tonnes per year are not yet available. However, the conceptual expanded project footprint (Figure A4.17-1) was superimposed on the reconnaissance-level soils map to determine the area of each soil unit that would be disturbed. The LSA was expanded for this exercise to include all of the expanded project footprint. As the Goma and Fwaulu pits were already assessed in the impact assessment, the main difference was the inclusion of the Fungurume pit and waste rock storage facilities. Areas projected to be disturbed could not be directly compared to soils within the RSA as soil mapping was not conducted for the RSA.

Mitigation

The same general principles used to develop the mitigation recommendations for the 115,000 tonnes of copper production per year scenario were used to develop the 400,000 tonnes per year scenario. A 400,000 tonnes per year project would need to develop a larger soil salvage, storage and reclamation plan. A more extensive erosion control and spill response plan would also be required.

Results

The effects of a larger, 400,000 tonnes per year project on soil quality/productivity and the loss of unique copper-cobalt soils would be greater in magnitude. A total of 3,092 hectares of soil will be disturbed during the operation phase of the expanded project (Table C 2.4-9). Most of the disturbance will occur in soil map unit 2 (1,670 hectares), soil map unit 3 (591 hectares) and soil map unit 1 (590 hectares).

After reclamation and closure, approximately 396 hectares will be fully reclaimed. It is assumed that the processing plant, roads, and topsoil piles will be returned to agricultural or miombo woodland that is able to support land uses similar to those that existed before disturbance. A total of 2,696 hectares will either remain disturbed or will be partially reclaimed to a self-sustaining plant community. This includes the following areas and disturbances:

- **Tailings storage facilities, waste rock facilities and low-grade ore stockpiles** – A topsoil layer will be placed over most of the areas covered by these facilities. Rock materials will be used as cover for the remainder. All topsoiled areas will be revegetated.
- **Plant sites and roads** – Plant sites and roads will be recontoured and revegetated unless communities want the roads to remain open and maintained.
- **Water reservoir** – The water reservoir will remain and will not be returned to terrestrial vegetation.
- **Mine pits** – Mine pits will be closed so that public safety is not at risk.

Most of the residual disturbance and partially reclaimed areas occurs in soil map unit 2 (1,431 hectares), soil map unit 3 (541 hectares) and soil map unit 1 (510 hectares).

Impact Analysis

The larger, 400,000 tonnes of copper production per year scenario will result in larger impacts throughout the LSA. To properly assess the magnitude of the effect, these losses would best be compared to the soil units available within the RSA. However, no soil map exists for the RSA. Therefore, the total projected soil loss (2,696 hectares) for the cumulative case was compared to the size of the RSA (48,000 hectares) to provide a rough estimate of the proportion lost. Using these figures, it is estimated that up to seven percent of the RSA's soils will be affected. This is equivalent to a low-impact magnitude.

Table C 2.4-9 Disturbance of Soil Map Units for Cumulative Case

Soil Map Unit	Area Occupied by Soil Unit (ha)	Loss from Project Development during Operations (ha)	Percent of Individual Soil Unit Disturbed Lost during Operations	Area of Disturbed Soil Fully Reclaimed after Closure (ha)[a]	Area of Disturbed Soil Partially Reclaimed after Closure (ha) [b]	Loss from Project Development after Closure (ha) [c]	Percent of Individual Soil Unit Disturbed Lost after Closure
1	2,148	590	27	79	390	510	24
2	7.858	1,670	21	239	813	1,431	18
3	3,641	591	16	50	294	541	15
4	477	33	07	10	21	23	5
5	221	28	13	0	16	28	13
6	131	127	97	0	2	127	97
7	295	20	7	14	4	6	2
8	8	3	38	3	0	0	0.5
9	36	30	85	2	0	28	79
Total	**14,816**	**3092**		**396**	**1539**	**2696**	

[a] An area fully reclaimed will have one meter of subsoil and a topsoil layer replacement and should support land uses (agriculture and miombo woodland) at a similar capability to that that existed prior to disturbance.

[b] An area partially reclaimed will have a layer of topsoil replacement and will support a self sustaining plant community.

[c] The loss after closure is the area disturbed during operations minus the land the is fully reclaimed.

Note: Due to rounding conventions, numbers may not equal totals.

ha = hectares.

The cumulative impacts of the expanded TFM project in the operation phase are predicted to be negative in direction, low in magnitude, regional in geographic extent, long term in duration, reversible and high frequency. The reversibility of impacts is assumed here because, during the operations phase, there is an opportunity to reverse some of the mine disturbance through reclamation. The environmental consequence of these effects is predicted to be low (Table C2.4-10).

Table C2.4-10 Residual Impact Classification for Cumulative Effects Case

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question $SR_{(ce)}$-1: What effect will the project have on soil quality/productivity?						
Operation Phase						
negative	low	regional	long-term	reversible	high	low
Closure Phase						
negative	low	regional	long-term	reversible	high	low
Key question $SR_{(ce)}$-2: What effect will the project have on loss of unique soils?						
Operation Phase						
negative	high	regional	long-term	reversible	high	high
Closure Phase						
negative	high	regional	long-term	reversible	high	high

The cumulative impacts of the expanded TFM project in the closure phase are predicted to remain low in magnitude (following all mitigation, including reclamation and closure), regional in geographic extent, long term in duration, reversible (following all mitigation, including reclamation and closure) and high frequency. The environmental consequence of these effects is predicted to be low (Table C2.4-10).

The expanded project would also result in a greater loss of unique copper-cobalt soils than those assessed in key question SR-2. A comparison of the effects to these soils within the RSA is not valid as the expanded project will be primarily located on copper-cobalt soils. The cumulative impacts in both the operation and closure phases are predicted to be high in magnitude, regional in geographic extent, long term in duration, reversible (following salvage, reclamation and closure), and high frequency. The environmental consequence of these effects is predicted to be high (Table C2.4-10).

Prediction Confidence

Information concerning the effects of a larger, 400,000 tonnes of copper production per year project is limited, but a general understanding of the effects

of such a project are in place. The prediction confidence for this assessment is limited by uncertainties in the accuracy of reconnaissance-level soil mapping, the effectiveness of soil salvage and reclamation of tropical soils, also limited information about the exact nature of the 400,000 tonnes per year scenario. Overall, the prediction confidence for the cumulative effects impacts on soil resources is moderate.

C2.4.5 Conclusions

Residual Impacts

The TFM project will have a moderate environmental consequence on soil quality/productivity during the operation phase. Following closure and reclamation, the project will have a low environmental consequence on soil quality/productivity. The project will have high environmental consequence for the loss of unique copper-cobalt soils in both the operation and closure phases (Table C2.4-11). Again, the reversibility of impacts is assumed based on opportunity to reverse some of the mine disturbance through reclamation. Overall, the prediction confidence for the TFM project on soil resources is moderate.

Table C2.4-11 Summary of Residual Impact Classification for Soil Resources

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question SR-1: What effect will the project have on soil quality/productivity?						
Operation Phase						
negative	moderate	local	long-term	reversible	high: occurs continuously	moderate
Closure Phase						
moderate	low	local	long-term	reversible	high: occurs continuously	moderate
Key question SR-2: What effect will the project have on loss of unique soils?						
Operation Phase						
negative	high	local	long-term	reversible	high	high
Closure Phase						
negative	high	local	long-term	reversible	high	high

Sustainability Effects

The overall sustainability consequence for sustaining soil quality/productivity based on proposed mitigation measures is moderate (Table C2.4-8). There is a high level of uncertainty in predicting the sustainability consequence since the span or reach and probability of success in implementing the mitigation measures is not clearly known at this time. The feasibility and appropriateness of the proposed mitigation measures also needs to be explored in more detail. Overall, the prediction confidence for sustaining soil quality/productivity is low due to these uncertainties.

Cumulative Effects

The cumulative development case looked at the impact of a project expansion from 115,000 tonnes of copper production per year to 400,000 tonnes per year. This would increase the disturbance footprint considerably. The expanded project would have a low environmental consequence on soil quality/productivity (Table C2.4-10). The expanded project would have a high environmental consequence for loss of unique soils. There is, however, more uncertainty in predicting the environmental consequence of a project expansion. Overall, the prediction confidence for the cumulative effects impacts on soil resources is moderate.

C2.5 VISUAL AESTHETICS IMPACT ASSESSMENT

C2.5.1 Introduction

This section presents the environmental assessment of the effects of Tenke Fungurume Mining project (the TFM project) on visual aesthetics as per the project's terms of reference (Section E8). The information presented includes details about:

- Potential issues regarding changes to visual aesthetics.
- Project activities that may affect visual aesthetics.
- Mitigation measures incorporated in the project design to minimize visual aesthetic impacts.
- Impact assessment approach and results for key visual aesthetics.
- Sustainability assessment approach and results for key visual aesthetics issues.
- Identified measures relating to visual aesthetics to promote long-term economic and social sustainability in the project area.
- Cumulative assessment approach and results for key visual aesthetic issues.

This section is organized as follows:

- Section C2.5.2 describes the study areas.
- Section C2.5.3 discusses the impact assessment approach and results.
- Section C2.5.4 provides the cumulative effects assessment.
- Section C2.5.5 discusses the conclusions of the assessment.

Baseline information concerning visual aesthetics has been provided in Section B2.5.

A glossary of terms and acronyms used is provided at the back of this volume.

C2.5.2 STUDY AREAS

The Regional Study Area (RSA) and Local Study Area (LSA) for the visual aesthetics impact assessments are provided in Section C1.5. The LSA for this assessment comprises a 7.5 kilometer radius circle around the Kwatebala ore body, a similar circle around the Goma ore body, the new access road between

the plant site at Kwatebala and Fungurume, and another 7.5 kilometer radius circle around the limestone quarry to the north of Fungurume (Figure C1.5-1). The Goma pits were included in the impact assessment as sufficient information was available to conduct the assessment as the time the work was carried out. An assessment of the Kavifwafwaulu (Fwaulu) pit was not conducted due to its relatively small size, low profile, distance from villages and late start-up date.

The RSA includes the LSA plus a 7.5 kilometer radius circle around the proposed future expansion plant site north of Fungurume (Figure C1.5-1).

Receptors for the assessment included the villages of Salabwe and Mwanga Muteba as these are the villages closest to the mine site. Owing to the close proximity of the villages of Mulumbu, Kiboko and Amoni to the preferred processing plant site, and the possibility of air and noise effects, the residents of these villages will be relocated. The assessment was therefore done on the assumption that their relocation will have been completed prior to the commencement of the mine development activities. These villages were therefore not used as receptors for the assessment. The site of Mulumbu was, however, used as a vantage point from which to view Kwatebala Hill and the processing plant.

C2.5.3 IMPACT ASSESSMENT

C2.5.3.1 ISSUE SCOPING

The visual impact associated with the proposed project was raised only once during the scoping process, by the dean of the polytechnical school in Lubumbashi. Visual issues are generally not considered to be important by people in an impoverished state, but this may change with time, particularly if the community's standard of living improves.

The activities of TFM that may potentially affect visual aesthetics include:

- Vegetation removal and soil stripping.
- Development of the pits (removal of Kwatebala, Goma and Fwaulu hills).
- Placement of waste rock and ore stockpiles.
- Construction of the processing plant site.
- Emission plumes from the processing plant.

Airborne dust caused by site clearing, materials handling, wind erosion of bare surfaces and by vehicles traveling along unpaved roads.

The main visual issues concern the visibility and intrusiveness of the mining, plant and infrastructure in relation to concentrations of people. In particular, the activities of the affected people are important – tourism facilities or conservation areas within the line of sight of the mining and mining infrastructure would be more sensitive to visual disturbance than other activities. No tourism, conservation or other highly visually sensitive land uses were identified during the scoping. Visual impacts are expected to be mainly along views from the National Road Number 1 between Fungurume and Tenke and from villages and towns in the LSA.

C2.5.3.2 KEY QUESTIONS AND INDICATORS

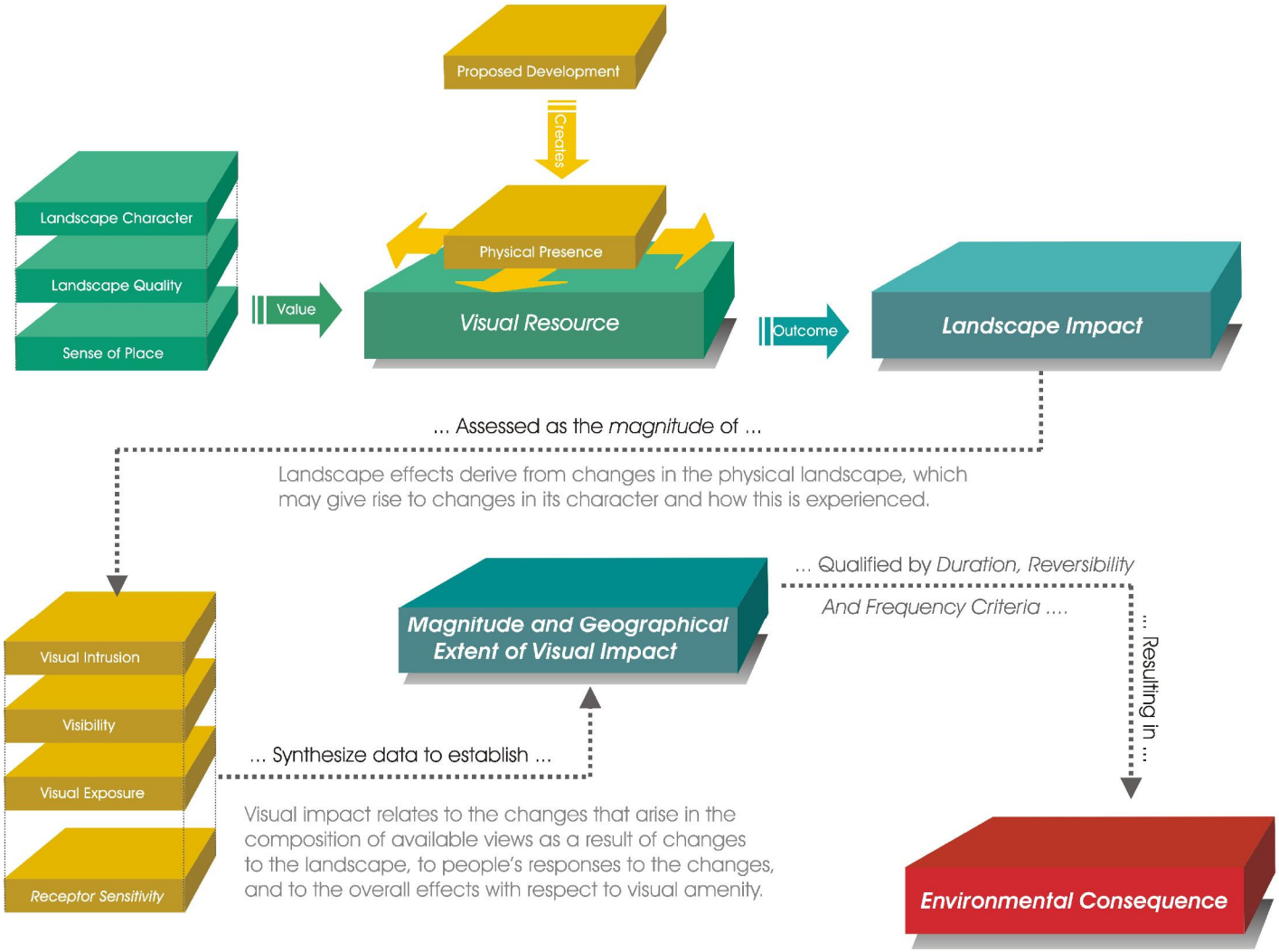
The key questions for visual aesthetics are listed in Table C2.5-1.

Table C2.5-1 Key Questions for Visual Aesthetics

Impact Assessment
VA-1 What effect will the Kwatebala mine, processing plant and associated infrastructure have on visual aesthetics?
VA-2 What effect will the access roads, power lines and limestone have on visual aesthetics?
VA-3 What effect will the Goma mine and its associated facilities have on visual aesthetics?
Sustainability Assessment
VA-4 How can the project influence the quality of the visual resource to have a long-term positive effect?

Indicators for visual aesthetics come from the visual impact process (Figure C2.5-1) and include:

- **Visual intrusion** – Significant change in landscape character, judged on the basis of the criteria described in Table C2.5-2.
- **Visibility** – The area/points from which the activity will be visible.
- **Visual exposure** – Visibility qualified with a distance rating and receptor identification to indicate the degree of public exposure of the project. Judged in accordance with number and location of receptors who can see the project infrastructure within a radius of approximately 7.5 kilometers. Beyond 7.5 kilometers, in hilly terrain, a large industrial project will begin to merge into the background. (The effects of distance on visual impact are shown in Figure C2.5-2).
- **Receptor sensitivity** – Ranking of activities into sensitivity categories. The measure includes the type of land use that is affected (for example, households, nature conservation, road users); each activity has a particular sensitivity to visual disturbance. The measure also uses the frequency with which visual issues were raised in stakeholder consultation as an indicator of stakeholder concern.



PROJECT/PROJET

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITLE/TITRE

VISUAL IMPACT ASSESSMENT PROCESS

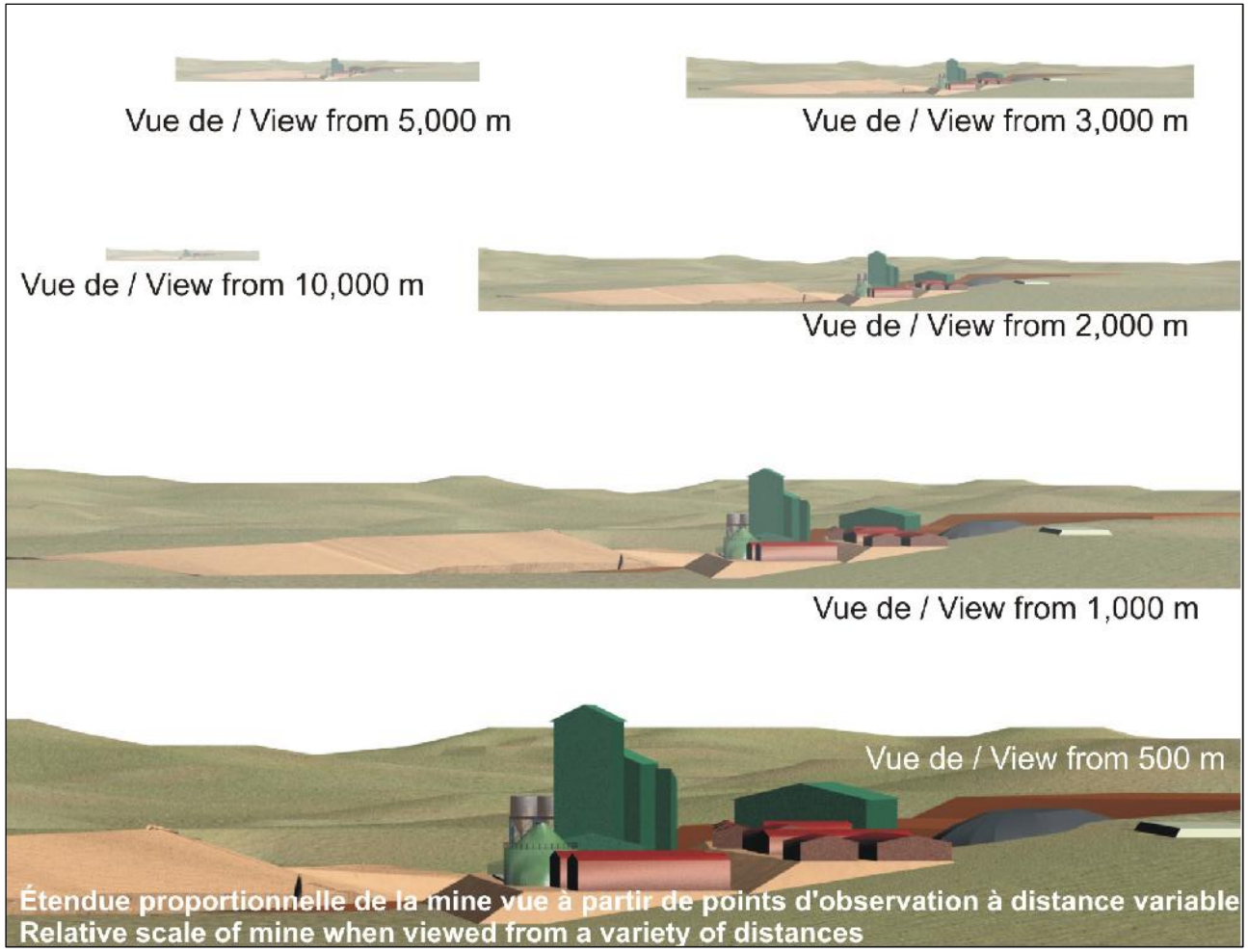
Golder Associates
Calgary, Alberta

PROJECT/PROJET	05-1334-035	
DESIGN/DESSIN	GJ	26/07/06
CADD/CAD	PSR	26/07/06
CHECK/VERIFIÉ	GJ	26/07/06
REVIEW/APPROUVÉ		

FILE No. Visual Impact EP
SCALE/ECHELLE AS SHOWN REV. 0

FIGURE: C2.5-1

R:\CAD\2005\1322-EA\1334\05-1334-035\6500\6520\JUNE29-2006\Fig C2.5-2 Visual Aesthetics.dwg Jul 19, 2006 - 2:57pm



PROJECT/PROJET

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITLE/TITRE

EFFET DE LA DISTANCE SUR L'IMPACT VISUEL DE LE PROJET
EFFECT OF CHANGES IN DISTANCE ON VIEWS OF THE PROJECT

Golder Associates
Calgary, Alberta

PROJECT/PROJET	05-1334-035	
DESIGN/DESSIN	MR	30/06/06
CADD/CAD	SWD	19/07/06
CHECK/VERIFIÉ	MR	19/07/06
REVIEW/APPROUVÉ		

FILE No. Visual Aesthetic
SCALE/ECHELLE AS SHOWN REV. 0

FIGURE: C2.5-2

C2.5.3.3 ASSESSMENT CRITERIA

Assessment criteria for visual aesthetics are presented in Table C2.5-2.

Table C2.5-2 Impact Description Criteria for Visual Aesthetics

Direction[a]	Magnitude (Intensity)[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
positive, negative or neutral for the measurement endpoints	**negligible:** visual impact causes very slight change in landscape character and affects few people and activities sensitive to visual change **low:** visual impact causes slight change to landscape character and affects few people and/or activities sensitive to visual change **moderate:** visual impact causes very noticeable change in landscape character and affects some people and/or activities sensitive to visual change **high:** visual impact causes major changes in landscape character and affects many people and/or activities sensitive to visual change	**local:** effect restricted to the LSA **regional:** effect extends beyond the LSA into the RSA	**short-term:** > 3 years **medium-term:** 3 to 20 years **long-term:** <20 years	reversible or irreversible	**low:** occurs once **medium:** occurs intermittently **high:** occurs frequently or continuously

(a) Direction: positive or negative effect for measurement indicators as defined for the specific component.
(b) Magnitude: degree of change to analysis indicator.
(c) Geographic Extent: area affected by the impact.
(d) Duration: length of time over which the environmental effects occurs. Considers a two-year construction period and a 20-year operations period.
(e) Reversibility: effect on the resource (or cannot be reversed).
(f) Frequency: how often the impact occurs.

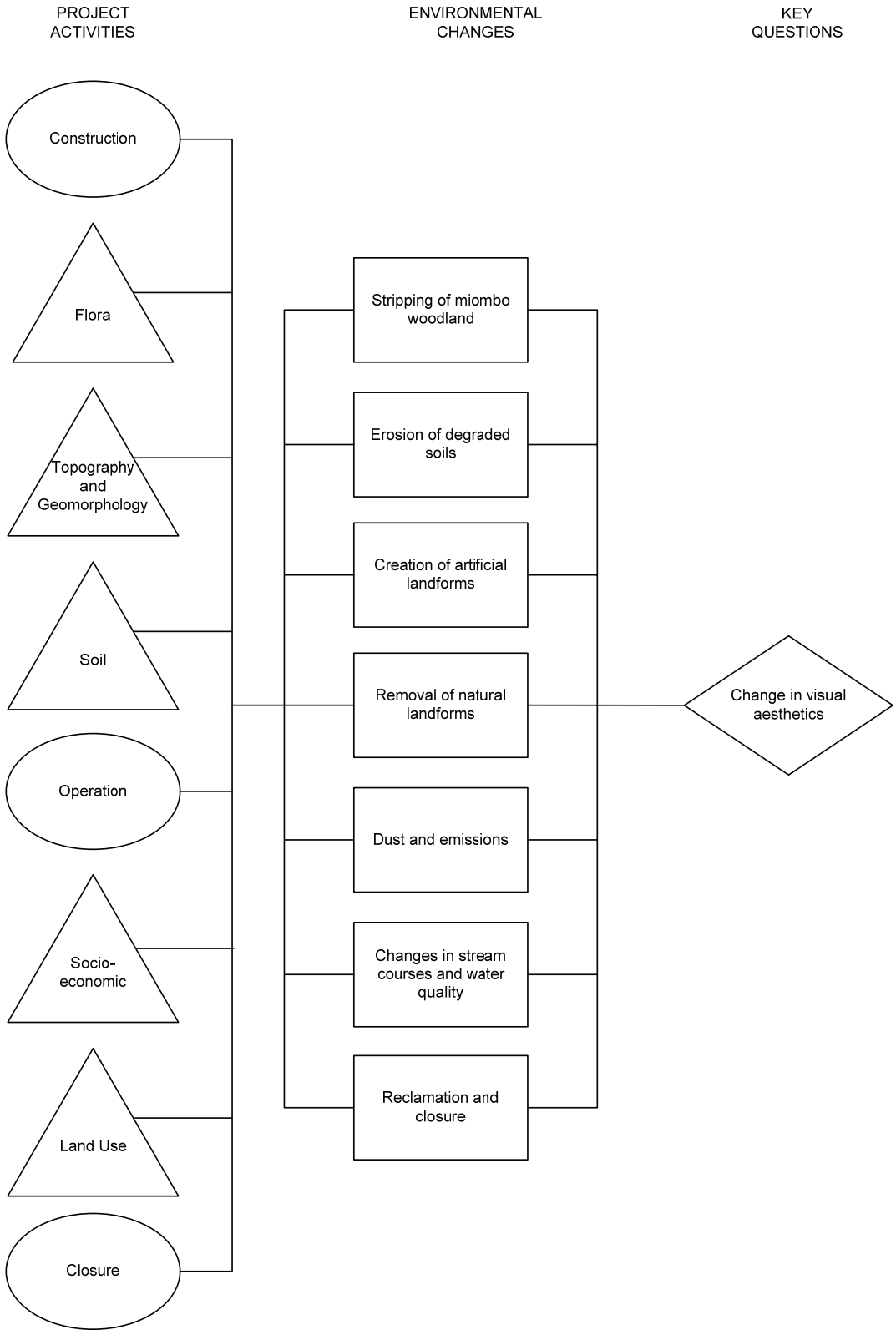
C2.5.3.4 Key Question VA-1

Key question VA-1 is: What effect will the Kwatebala mine, processing plant and associated infrastructure have on visual aesthetics?

Linkage Evaluation

The visual impacts are linked, in a cause and effect relationship, to the clearing of vegetation during construction. The visual impacts are also linked to the changes in topography and geomorphology that will result from the proposed development, and to the plant design and the air quality management actions practiced (Figure C2.5-3). Dust raised by site clearing, materials handling, wind erosion of bare surfaces and vehicles traveling along unpaved roads will also be visible. Significant emissions of particulate matter and visible mist from the sulfuric acid plant stack would not only signify possibly unacceptable air pollution, but would also be visually intrusive. Changes in land use and socio-economic conditions attracting migrants into the area could cause large-scale changes in visual aesthetics as a result of the need to clear miombo woodland for agriculture. Disturbance of stream courses and water quality could also have visual aesthetic effects. Finally, reclamation and closure will help to reduce some of the effects to visual aesthetics during closure.

Figure C2.5-3 Visual Aesthetics Linkage Diagram



In the absence of important heritage issues there are no forward linkages from visual impact to other topic areas.

Assessment Methods

Plans for the mine, processing plant and ancillary infrastructure were reviewed in the context of the known baseline conditions for visual aesthetics. The indicators defined in Section C2.5.3.2, namely visual intrusion, visibility, visual exposure and receptor sensitivity were assessed individually and then combined, using professional experience, as the basis for the evaluation of visual impact (Figure C2.5-1).

Visual intrusion was measured in accordance with a qualitative structured rating scale in a negative direction from high to negligible, or in a positive direction (Table C2.5-3). Visual simulations were prepared which show the appearance of the different elements of the project in the landscape. The rating scale in Table C2.5-3 was then applied, using the simulations as a measure of change.

Table C2.5-3 Measurement of Visual Intrusion

High	Moderate	Low	Negligible	Positive
if the proposed activity: - has a substantial negative effect on the visual quality of the landscape - contrasts dramatically with the patterns or elements that define the structure of the landscape - contrasts dramatically with land use, settlement or enclosure patterns - is unable to be 'absorbed' into the landscape	**if the proposed activity:** - has a moderate negative effect on the visual quality of the landscape - contrasts moderately with the patterns or elements that define the structure of the landscape - is partially compatible with land use, settlement or enclosure patterns (tourist cottages and estates in the general area) - is partially 'absorbed' into the landscape	**if the proposed activity:** - has a minimal effect on the visual quality of the landscape - contrasts minimally with the patterns or elements that define the structure of the landscape - is mostly compatible with land use, settlement or enclosure patterns - is 'absorbed' into the landscape	**if the proposed activity:** - has no effect, or an effect that is not measurable	**if the proposed activity:** - has a beneficial effect on the visual quality of the landscape - enhances the patterns or elements that define the structure of the landscape - is compatible with land use, settlement or enclosure patterns
result: notable change in landscape characteristics over an extensive area and/or intensive change over a localized area	**result:** moderate change in landscape characteristics over a localized area	**result:** imperceptible change in landscape characteristics	**result:** negligible change in landscape characteristics	**result:** positive change in landscape characteristics

Visibility was measured using geographic information system (GIS) viewshed analysis. A viewshed is all areas from which a reference point can be seen by an observer. Selected points (generally worst case) were selected as the reference points from which viewsheds were determined. For example, the visibility of mining at Kwatebala was taken from the highest point of the hill. Visibility of the processing plant was measured from an elevation ten meters above the ground in the center of the plant area.

Visual exposure was determined from the viewsheds, from available mapping of the study area and from the ESIA mapping of land use within the 7.5 kilometer cut off zone, beyond which visual impacts in this type of terrain become insignificant. Visual exposure takes the index of visibility and adjusts it for distance from the view and the number of people who see it (or could see it in the future).

Receptor sensitivity was determined from a knowledge of land use within the study area and from the results of the stakeholder consultation during the course of the ESIA, in which issues raised by members of the public and the government were captured.

Mitigation

The following mitigation measures will be initiated as practical during the construction phase to minimize impacts on visual aesthetics and will continue to be implemented during the operation phase of the project.

- Bush clearance should be kept to the minimum necessary for the construction of the plant, the mining infrastructure, the limestone quarry, the access road, the power line, and ancillary facilities.
- Every effort will be made to leave as many trees intact as possible, especially those that will contribute to screening of the development from view.
- To ensure that trees around the perimeter of the development areas are not lost unnecessarily, the construction area will be fenced or, in cases where this is not practical, trees that are not to be removed will be marked with paint.
- The design of the plant and buildings should make use of earth colors and avoid bright and reflective colors.
- Planting of clusters of native trees around the perimeter of the facility will soften its intrusiveness. TFM should plant fast-growing indigenous trees at the end of the construction phase.
- After consultation with potentially affected villages, planting of indigenous trees at the edges of the villages facing the facilities may be

done to help screen the inhabitants of Salabwe, Mwanga, Mwanga Sangu and Mulumbu Kiasa from views of the facilities. The concurrence and cooperation of the local village leaders and population in planting and maintaining the trees will be necessary to implement this mitigation.

- Fast-growing indigenous trees will be planted in a dense screen along the boundary of the town of Tenke, and at the perimeter of the limestone quarry, subject to agreement with local stakeholders. This simple but effective means of visual screening will be undertaken during the construction phase of the Kwatebala mine, giving the trees the chance to grow to maturity before mining at Goma and Fwaulu starts.
- Some portions of the final outer slopes of the tailings dam walls that are not buttressed by waste rock are suitable for rehabilitation. These sections will be rehabilitated concurrently as the facility is being constructed. This will be achieved by placing topsoil on the slopes and encouraging native grasses to establish, within limits of technology under development through the BDAP (Appendix D3.1-II). As the height of the walls is increased incrementally, the additional sections of walls that will form final exposed surfaces will be rehabilitated.
- Dust plumes caused by construction activities, wind erosion of bare surfaces and vehicles traveling along unpaved roads will be controlled by wet suppression or, where insufficient water is available, by a commercial dust suppressant.
- Unless site security or safety may be compromised, the use of outside lighting that projects downward will be considered over flood lights.
- Installation of an alkaline scrubber in the sulfuric acid plant stack will minimize or eliminate visible plumes. A sulfuric acid plant stack normally only emits a visible plume for a short period of time (15 to 30 minutes) after a cold startup, or for a few minutes if certain upset conditions occur during normal operation.
- Dust plumes from waste rock blasting will be reduced by judicious design of the blast to prevent the ejection of fly rock and dust into the air.

A management program will be implemented for copper-cobalt miombo and gallery forests vegetation types (Section D3.1.13) and for conservation of a portion of the unique topography (sinuous, low hills) (Section C2.1). A land use management plan will be developed that has visual aesthetics as one of its guiding principles, and which will be discussed with the local authority and local communities, (Section C3.1).

Results

Visual simulations showing the processing plant and the waste rock facility are shown in Figures C2.5-4 to C2.5-7, as seen from Mulumbu, Salabwe and Mwanga, together with the existing views from the same locations. Visual simulations were prepared for Mulumbu even though this village will be relocated during or prior to construction. These simulations represent a 'worst case scenario' for someone standing close to the mine. Figures C2.5-7 shows ground level and aerial views of the processing plant. Figures C2.5-8 to C2.5-10 present viewsheds of Kwatebala Hill, and future viewsheds of the processing plant and the waste rock facility.

Impact Analysis

Visual Intrusion: The magnitude of change in the landscape that will be caused by the mine and processing plant will be moderate at Mwanga Muteba (Figure C2.5-6) and Salabwe (Figure C2.5-5) and high at Mulumbu (Figure C2.5.4). There will be intensive alteration of landscape characteristics over a moderately large area during construction of the mine and plant and operation of the mine. The visual quality of the existing landscape is high and the introduction of a major industrial facility into this setting will contrast significantly with the existing patterns of land use and the natural habitats. Because of the scale of the facility, a local change in visual quality may be expected (Figures C2.5-4 to C2.5-6). In addition to the physical changes to the landscape, caused by the initial clearing of vegetation for the mine and the construction of the processing plant, visual intrusion will be caused by the ongoing operation of the mine, the movement of heavy vehicles and the generation of dust on unpaved roads around the mining area, between the mine and the waste rock stockpile and on the tailings dam. Subject to the proposed mitigation, the magnitude of visual intrusion caused by dust impact should be low to moderate.

Visibility and Visual Exposure: Visibility of the mine, the plant, the waste rock and the tailings storage facility will be moderate (refer to Figures C2.5-8 to C2.5-10). The viewsheds are based on topography only and do not take the screening effects of vegetation into account. The extent of visibility illustrated in the figures is therefore conservative, since miombo woodland has a major influence on visibility in the LSA (refer to Photographs C2.5-1 and C2.5-2). The viewsheds also show the most visible areas, being derived for points on the top of Kwatebala Hill, from ten meters above ground level at the processing plant, and from the top of the waste rock facility. The viewsheds therefore represent worst case theoretical visibility of the mining and mining infrastructure.

Mont Kwatebala, vu depuis la lisière ouest du village de Mulumbu / Kwatebala Hill, viewed from the western edge of Mulumbu village

Usine de traitement avec le mont Kwatebala en arrière-plan, au début de l'exploitation minière, vue depuis la lisière ouest du village de Mulumbu (simulation visuelle) / Processing plant with Kwatebala Hill in the background, showing mining during the early mining period, viewed from the western edge of Mulumbu village (visual simulation)

NOTES

Les résidents de la maison seront relocalisés.
Residents of house in foreground will be relocated.

PROJECT/PROJET

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITLE/TITRE

VUES ACTUELLE ET FUTURE DU MONT KWATEBALA ET DE L'USINE DE TRAITEMENT DEPUIS MULUMBU
CURRENT AND FUTURE VIEWS OF KWATEBALA HILL AND THE PROCESSING PLANT FROM MULUMBU

Golder Associates
Calgary, Alberta

PROJECT/PROJET	05-1334-035		FILE No.	Curnt-Fut-Process Plt
DESIGN/DESSIN	MR	30/06/06	SCALE/ECHELLE	AS SHOWN
CADD/CAD	SWD	02/04/07	REV.	0
CHECK/VERIFIE	MR	19/07/06		
REVIEW/APPROUVE				

FIGURE: C2.5-4

R:\CAD\2005\1322-EA\1334\05-1334-035\6500\6520\JUNE29-2006\Fig C2.5-5_Current-Future Views-Kwatebala waste rock facility from salabwe.dwg Jul 19, 2006 - 2:56pm

Zone où les haldes de stériles seront situées, vue depuis Salabwe / The area in which the waste rock facility will be situated, viewed from Salabwe

Les haldes de stériles vues depuis Salabwe (simulation visuelle) / The waste rock viewed from Salabwe (visual simulation)

PROJECT/PROJET

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITLE/TITRE

VUES ACTUELLE ET FUTURE DES HALDES DE STÉRILES DE KWATEBALA DEPUIS SALABWE / CURRENT AND FUTURE VIEWS OF THE KWATEBALA WASTE ROCK FACILITY FROM SALABWE

Golder Associates
Calgary, Alberta

PROJECT/PROJET	05-1334-035	
DESIGN/ DESSIN	MR	30/06/06
CADD/CAD	SWD	19/07/06
CHECK/ VERIFIÉ	MR	19/07/06
REVIEW/ APPROUVÉ		

FILE No. Kwate waste-Salabwe
SCALE/ ECHELLE AS SHOWN REV. 0

FIGURE: C2.5-5

Zone où les haldes de stériles seront situées, vue depuis Mwanga / The area in which the waste rock facility will be situated, viewed from Mwanga

Les haldes de stériles vues depuis Mwanga (simulation visuelle) / The waste rock facility viewed from Mwanga (visual simulation)

PROJECT/PROJET

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

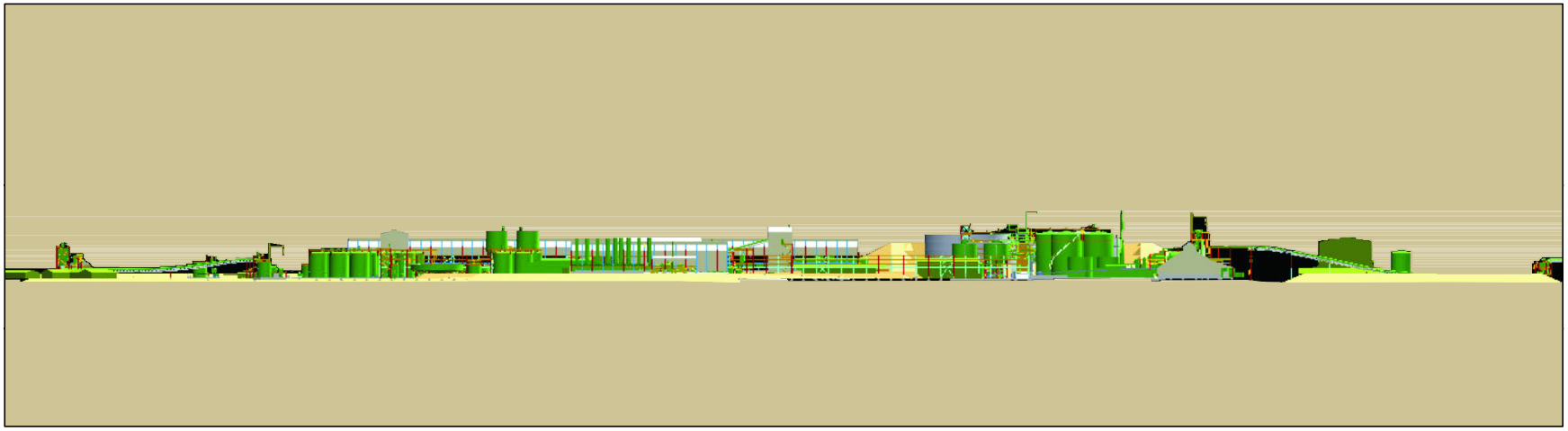
TITLE/TITRE

VUES ACTUELLE ET FUTURE DES HALDES DE STÉRILES DE KWATEBALA DEPUIS MWANGA
CURRENT AND FUTURE VIEWS OF KWATEBALA WASTE ROCK FACILITY FROM MWANGA

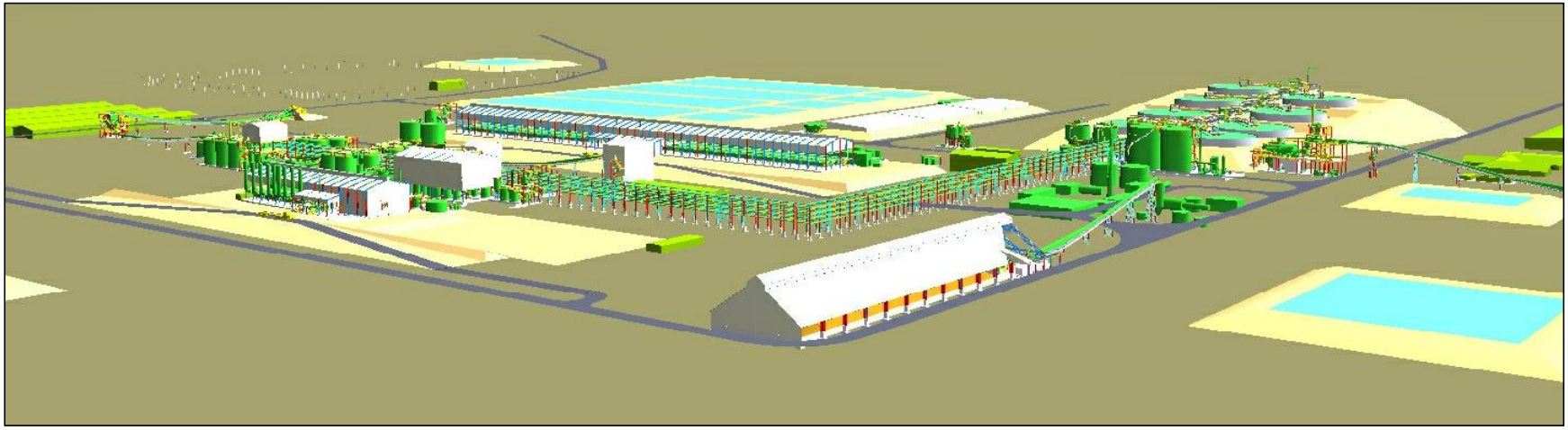
Golder Associates
Calgary, Alberta

PROJECT/PROJET	05-1334-035		FILE No.	Kwate waste-Mwanga
DESIGN/DESSIN	MR	30/06/06	SCALE/ECHELLE	AS SHOWN REV. 0
CADD/CAD	SWD	19/07/06		
CHECK/VERIFIÉ	MR	19/07/06		
REVIEW/APPROUVÉ				

FIGURE: C2.5-6



L'usine de traitement - vue au niveau du sol / The processing plant - ground level view



L'usine de traitement - perspective aérienne / The processing plant - aerial perspective

PROJECT/PROJET

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

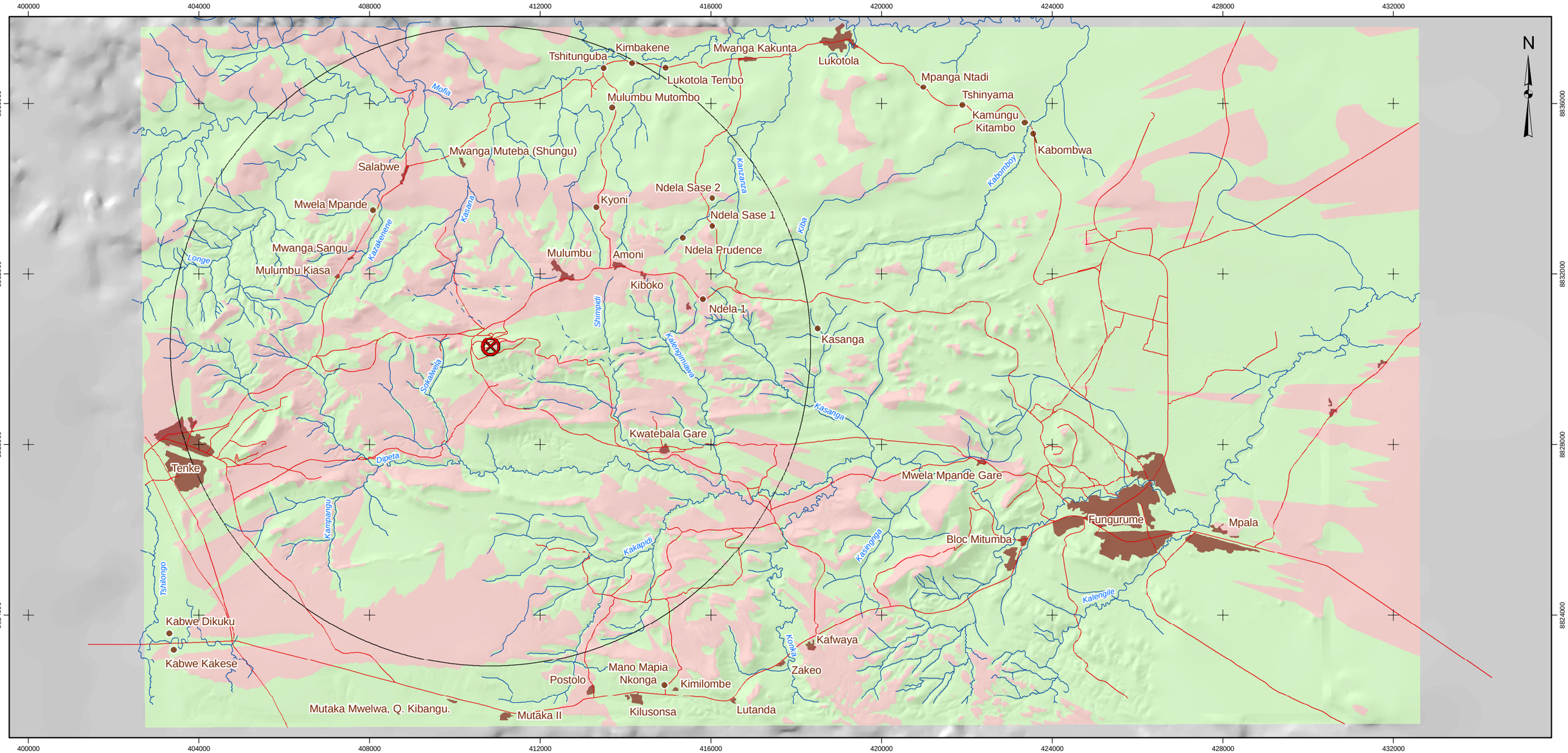
TITLE/TITRE

L'USINE DE TRAITEMENT -
AU NIVEAU DU SOL ET PERSPECTIVES AÉRIENNES
THE PROCESSING PLANT -
GROUND LEVEL AND AERIAL PERSPECTIVES

Golder Associates
Calgary, Alberta

PROJECT/PROJET	05-1334-035		FILE No.	ProPlt -Gr-Air-Persp
DESIGN/ DESSIN	MR	12/07/06	SCALE/ ECHELLE	AS SHOWN REV. 1
CADD/CAD	PSR	29/03/07		
CHECK/ VERIFIÉ	GJ	29/03/07		
REVIEW/ APPROUVÉ	MR	29/03/07		

FIGURE: C2.5-7



LÉGENDE / LEGEND

- EMPLACEMENT DU POINT D'OBSERVATION DE LA ZONE DE VISIBILITÉ DU MONT KWATEBALA / KWATEBALA VIEWSHED POINT
- VILLAGE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- RÉGION D'INFLUENCE VISUELLE (LA ZONE D'ÉTUDE LOCALE) / ZONE OF VISUAL INFLUENCE (LOCAL STUDY AREA)

ZONE DE VISIBILITÉ DE KWATEBALA / KWATEBALA VIEWSHED

- NON VISIBLE / NOT VISIBLE
- VISIBLE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE / SCALE 1:90000 1:90000 KILOMÈTRES / KILOMETERS

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

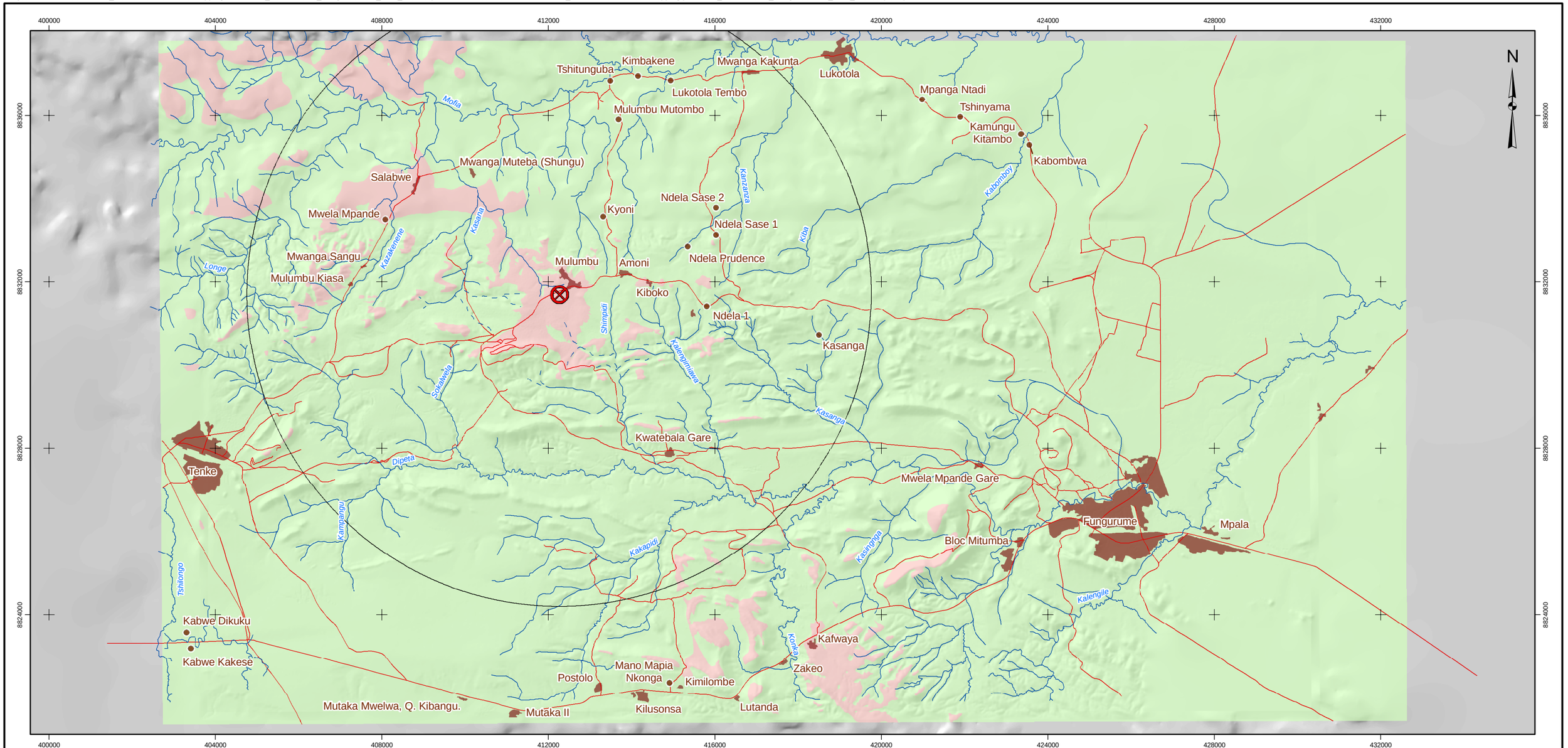
ZONE DE VISIBILITÉ À PARTIR DU POINT LE PLUS ÉLEVÉ DU MONT KWATEBALA / VIEWSHED FROM THE HIGHEST ELEVATION ON KWATEBALA HILL

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035		ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	MW	10 Jun. 2006	
GIS / SIG	TN	04 Jan. 2007	
VÉRIFIÉ / CHECK	MR	20 Jul. 2006	
APPROUVÉ / REVIEW	MR	31 Jul. 2006	

FIGURE: C2.5-8

Project: I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\mxd\Tenke_ESIA\Volume_C\FigureC2.5-9_View_Processplant.mxd - Plot: I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\pdf\Tenke_ESIA\Volume_C\FigureC2.5-9_View_Processplant.pdf



LÉGENDE / LEGEND

- POINT OBSERVÉ POUR LA ZONE DE VISIBILITÉ DU SITE DE L'USINE (10 MÈTRES AU-DESSUS DE L'ÉLÉVATION DU SOL) / PLANT SITE VIEWSHED POINT (10M ABOVE GROUND ELEVATION)
- VILLAGE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- RÉGION D'INFLUENCE VISUELLE (LA ZONE D'ÉTUDE LOCALE) / ZONE OF VISUAL INFLUENCE (LOCAL STUDY AREA)

ZONE DE VISIBILITÉ DU SITE DE L'USINE / PLANT SITE VIEWSHED

- NON VISIBLE / NOT VISIBLE
- VISIBLE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE / SCALE 1:90000 / 1:90000 KILOMÈTRES / KILOMETERS

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

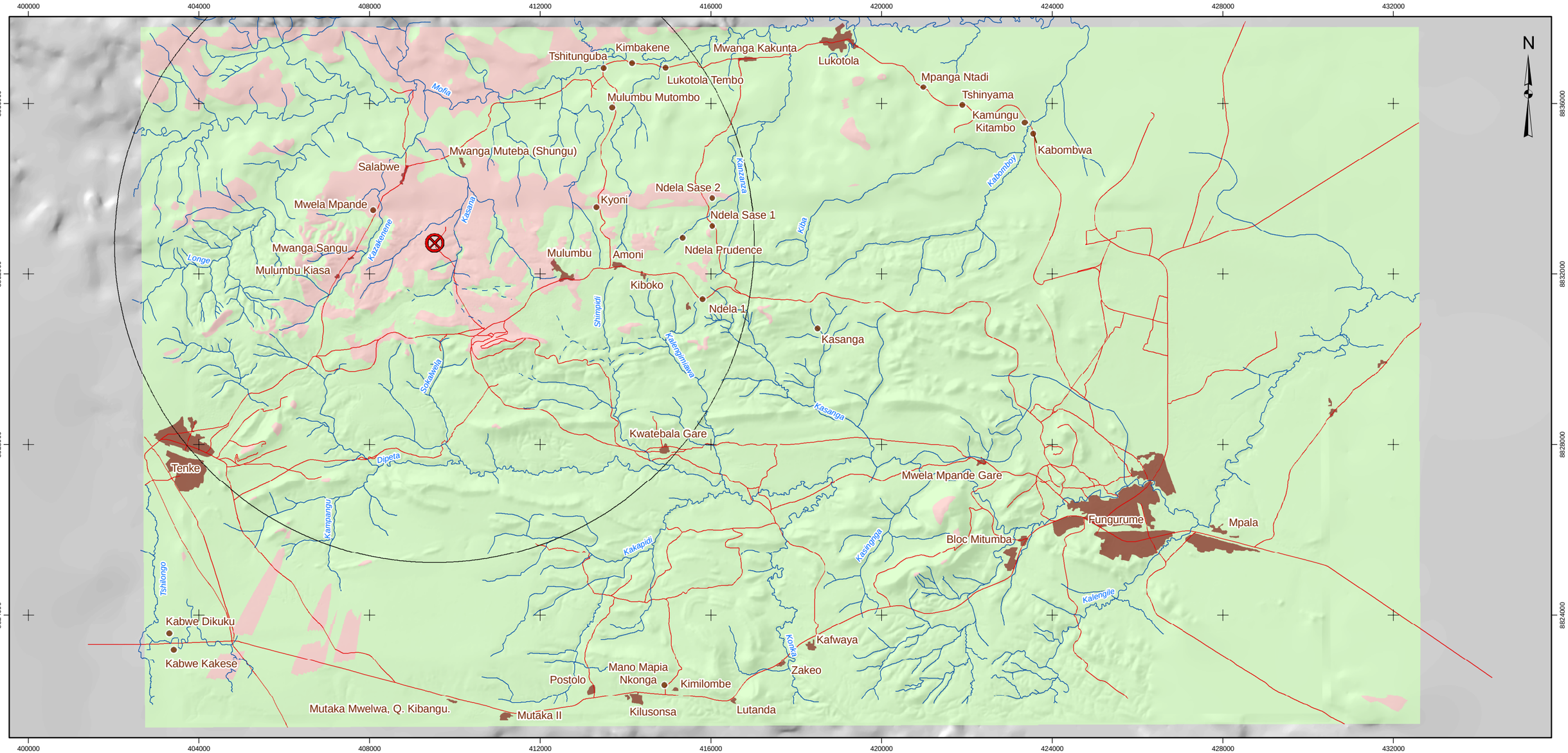
TITRE / TITLE

ZONE DE VISIBILITÉ DE L'USINE DE TRAITEMENT, 10 MÈTRES AU-DESSUS DU NIVEAU DU SOL / VIEWSHED FROM THE PROCESSING PLANT, 10 METERS ABOVE GROUND LEVEL

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035		ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	MW	10 Jun. 2006	
GIS / SIG	TN	04 Jan. 2007	
VÉRIFIÉ / CHECK	MR	20 Jul. 2006	
APPROUVÉ / REVIEW	MR	31 Jul. 2006	

FIGURE: C2.5-9



LÉGENDE / LEGEND

- EMPLACEMENT DU POINT D'OBSERVATION DE LA ZONE DE VISIBILITÉ DE LA HALDE À STÉRILES / WASTE ROCK FACILITY VIEWSHED POINT (HIGHEST POINT)
- VILLAGE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- RÉGION D'INFLUENCE VISUELLE (LA ZONE D'ÉTUDE LOCALE) / ZONE OF VISUAL INFLUENCE (LOCAL STUDY AREA)

ZONE DE VISIBILITÉ DU SITE DE L'USINE / WASTE ROCK FACILTY VIEWSHED

- NON VISIBLE / NOT VISIBLE
- VISIBLE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE 1:90000 KILOMÈTRES
SCALE 1:90000 KILOMETERS

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

ZONE DE VISIBILITÉ DU POINT LE PLUS ÉLEVÉ ET LE PLUS AU NORD DES HALDES À STÉRILES / VIEWSHED FROM THE WASTE ROCK FACILITY AT THE HIGHEST AND MOST NORTHERLY POINT

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035		ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	MW	10 Jun. 2006	
GIS / SIG	TN	04 Jan. 2007	
VÉRIFIÉ / CHECK	MR	20 Jul. 2006	
APPROUVÉ / REVIEW	MR	31 Jul. 2006	

FIGURE: C2.5-10

Photograph C2.5-1 **Miombo Woodland in the Study Area Which Minimizes Visibility of Other Areas**

Photograph C2.5-2 **Miombo Woodland in the Study Area, Showing the Patchwork of Open and Closed Areas and the Effect This Has on Visibility in the Study Area**

The hilly terrain in which the project is situated results in fragmented viewsheds which do not extend, uninterrupted, over long distances. Even the top of Kwatebala Hill, which is the highest point in the area, is not visible over extensive areas (Figure C2.5-8). East of Kwatebala, there are few vantage points from which the hill is visible, owing to the complex topography. On the western side, Kwatebala will be visible from the Goma hills. To the north and south, the terrain dips into the Mofia and Dipeta river valleys, and Kwatebala Hill disappears from view, becoming visible again from the high ground in the north, along the Mofia Plateau some eight kilometers distant, and in the south along the prominent ridge which runs parallel to the National Road Number 1 east of Tenke.

Visual exposure to mining of Kwatebala Hill will be limited to the villages of Salabwe (population 235), Mwanga Muteba (153), Mwanga Sangu (35) and Mulumbu Kiasa (113). Slight distortion of the contour data results in the visibility of the hill from Mwanga Muteba not being apparent from Figures C2.5-8 to C2.5-10. The villages of Mulumbu, Amoni and Kiboko would have been in clear view, but TFM proposes to resettle these communities before mine operation begins and the views are consequently not considered in the analysis.

The mining of Kwatebala Hill will not be exposed to view from Fungurume and will be seen only from the northern end of Tenke. At distances greater than about 7.5 kilometers, the visual exposure of communities to views of the mining will be negligible even if in full (theoretical) view. Tenke is about eight kilometers distant. Visual exposure of other communities to views of mining on Kwatebala Hill will also be negligible.

When the screening effect of miombo woodland is taken into consideration, the actual visual exposure of populations around the mine is very limited and is significantly less than that forecast by the viewshed analysis. Photographs C2.5-1 and C2.5-2 show some of the typical patterns of miombo in the study area. It is, for example, difficult to find a location in Mwanga in which a view of Kwatebala is not obscured by miombo. Overall visibility of the mine is considered to be moderate, while the visual exposure of populations to the view is low.

The processing plant is situated below and immediately to the northeast of Kwatebala Hill and will be less visible in the surrounding landscape than the first phase of mining, being at a lower elevation. The plant will be visible northward past Salabwe and Mwanga (Figure C2.5-9). To the south, it will be visible over a almost totally hidden from view, with the exception of distant views from the hills south of Kafwaya, some ten kilometers away.

Theoretically, the plant will be exposed to views from Salabwe at a distance of about four or five kilometers. No other villages will be in view. The plant will be screened from the southwest as a result of Kwatebala Hill - while this will change once the hill has been mined away, visibility will continue to be limited. Overall, visibility of the processing plant is considered to be moderate, while visual exposure of the local population to the view will be low.

The tailings storage facility will be a valley fill and will be visible only from the immediate surrounding area. The waste rock facility, which is proposed adjacent to and immediately northeast of the tailings storage facility, will be visible in the immediate vicinity of the waste rock facility, with views extending northward to just beyond Salabwe and Mwanga (Figures C2.5-5 and C2.5-6 and Figure C2.5-10). Beyond the Mofia River, the waste rock facility will again be visible in the distance from the rising terrain leading up to the Mofia plateau. The dump will be invisible to the south, beyond Kwatebala Hill. Visually exposed villages will include Salabwe and parts of Mwanga, as well as the small hamlets of Mulumbu Kiasa and Mwanga Sanga.

Overall, visibility of the waste rock facility will be moderate and visual exposure of local populations to the view will be moderate.

Taking into consideration the small number of people who currently reside within the line of sight of the mine, the processing plant, the waste rock facility and the tailings storage facility, the distance from these imposed features and the screening effect of the existing local vegetation, the actual visibility and visual exposure of people to these facilities is rated as low to moderate. This could increase to moderate over time, if substantially more people settle in the area and if the vegetative cover is significantly reduced.

Receptor Sensitivity: A wide range of stakeholders were consulted during the public consultation process, including the Democratic Republic of the Congo (DRC) authorities, both local and central, local businesses, non-governmental organizations (NGOs) within and beyond the project area, tribal authority structures and local inhabitants. The impact of the project on scenic quality was raised only once, by the Dean of the polytechnical school in Lubumbashi. When made aware of such impacts, most stakeholders were indifferent, but some indicated that they would view the visible presence of the development in a positive light, as a sign of economic progress that could benefit them.

Considering the impoverished state of the people in the region, it is understandable that they would rank the prospect of an improvement in their material well-being above the scenic beauty of their surroundings. This attitude reflects their current socio-economic status rather than signaling an inherent

indifference towards aesthetic values. Over time, their priorities may change as investment in the region brings about improvements in their material well-being.

No visually sensitive land uses, such as conservation areas, tourism facilities or other areas (existing or planned) in which views are considered to be important exist within the LSA. The nearest recognized conservation area is the Upemba National Park, the southern boundary of which is approximately 75 kilometers north of the LSA (Figure B1.2-1). Receptor sensitivity to the mining development will therefore be limited to the villages described and to road users close to Tenke. Currently, and for the next decade at least, local stakeholder concern about scenic quality is likely to remain low. The sensitivity of the exposed population to visual change will therefore be low.

Magnitude of Visual Impact: While the visual intrusion caused by the facility is expected to be high, the overall magnitude of impact of the proposed development in terms of key question VA-1 is rated as low to moderate, taking into consideration the small number of people affected by the views, the limited visibility from these communities, the lack of sensitivity of the communities to visual disturbance and the absence of other visually sensitive land uses in the areas exposed to view (Table C2.5-4).

Table C2.5-4 Residual Impact Classification for Key Question VA-1

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question VA-1: What effect will the Kwatebala mine processing plant and associated infrastructure have on visual aesthetics?						
Construction Phase						
negative	moderate	local	long-term	no	high	moderate
Operation Phase						
negative	low to moderate	local	long-term	yes	high	low to moderate
Closure Phase						
negative	low	local	long-term	yes	high	low to moderate

The overall residual impact (environmental consequences, based on the screening system in Volume A, Table A5.9-2) are considered to be low to moderate for all three phases of development (construction, operation, closure).

Prediction Confidence

The predictions are based on quantitative assessment of visibility, visual simulation of effects and analysis of population exposure and sensitivity. There

are no known uncertainties that could significantly alter the assessment and the prediction confidence is therefore rated as high.

Monitoring

Monitoring during the construction phase will verify that vegetation clearance is kept to a minimum (Section D3.1.12) and that dust is kept to acceptable levels (Section D3.1.3). Monitoring of dust (for aesthetic purposes) during the project operational phase will be done by observation using qualitative structured procedures to check and record dust blow from the various mining and mining infrastructure facilities. Dust plume monitoring will include those caused by blasting, materials handling and vehicular traffic and tailings wind blow (Section D3.1.3). The planting of trees as visual screens will be monitored, as will mine site landscaping.

Monitoring of erosion control and rehabilitation will include structured assessment of the re-establishment of indigenous grass cover (Section D3.1.12). Monitoring of the effectiveness of erosion control, slope stability and rehabilitation measures are described in Section D3.1. Further details on monitoring are provided in Section 3.1.2.

C2.5.3.5 Key Question VA-2

Key question VA-2 is: What effect will the access roads, power lines and limestone quarry have on visual aesthetics?

Linkage Evaluation

The visual impacts are linked, in a cause and effect relationship, to the changes in vegetation structure caused by clearing of miombo woodland and to air quality management actions practiced. Dust raised by blasting, materials handling and traveling along unpaved roads will greatly increase the visibility of these activities. The linkages will be the same as described in Figure C2.5-3 for key question VA-1.

Assessment Methods

Plans for the limestone quarry and ancillary infrastructure were reviewed in the context of the known baseline conditions for visual aesthetics. The indicators defined in Section C2.5.3.2, namely visual intrusion, visibility, visual exposure and receptor sensitivity were assessed individually and were then combined, using professional experience as the basis for the evaluation of visual impact.

The study measured visual intrusion in accordance with a qualitative structured rating scale in a negative direction (from high to low - Table C2.5-3). Visibility

was not quantified, but was judged in accordance with the physical attributes of the features and the landscape. Visual exposure was determined from the environmental and social impact assessment (ESIA) mapping of land use within the 7.5 kilometer cut-off zone, outside of which visual aesthetic impacts are expected to be insignificant. Receptor sensitivity was determined from knowledge of land use within the study area and from the results of the stakeholder consultation during the course of the ESIA, in which issues raised by members of the public and the government were captured.

Mitigation

The access road and power line routes and the limestone quarry are not located near large human settlements, subject to the villages of Mulumbu, Kiboko and Amoni being resettled as planned. The following mitigation measures will be employed to minimize impacts on visual aesthetics:

- **Management of Dust Impact**: During construction and operation of the road and quarry and construction of the power line, dust plumes will be managed by wet suppression or, where insufficient water is available, by a commercial dust suppressant (Section D3.1.3).
- **Vegetation Screening**: As much of the existing vegetation as possible will be left intact during construction of the linear infrastructure. The miombo woodland will be a highly effective screen of all project activities. At the limestone quarry, fast-growing indigenous trees will be planted at the perimeter of the area under the direct control of the mine in the early stages of the mining development.

Impact Analysis

Visual Intrusion: The limestone quarry is located approximately 10 kilometers north of Fungurume and three kilometers west of the airfield. It will cause intensive alteration of landscape characteristics over a small area. The visual quality of the existing landscape is moderate to high and the insertion of the quarry will contrast significantly with the existing patterns of land use and natural habitats. A significant but highly localized change in visual quality is expected.

The access road and the power line will be linear intrusions across the same landscape, contrasting with existing patterns of land use and natural habitats and causing localized changes in visual quality. Unless mitigated, the visual intrusion of dust generated by traffic on the access road will be more significant than the appearance of the road itself.

Visibility and Visual Exposure: Details of the mine plan for the limestone quarry are not available but the location is well established. The quarry will be visible only from limited perspectives up to 7.5 kilometers away (Figure C2.5-11) due to the location of the quarry in reasonably level terrain covered in arable grassland and open woodland. Depending on the direction of flight, it will be visible from aircraft taking off and landing at the airfield.

The access road and power line will cross undulating terrain characterized by arable land and open woodland. The power line will generally be most visible up to approximately 500 meters away and where it crosses ridgelines. The road will be similarly visible, and will be seen mainly in short sections entering and leaving woodland patches. Visibility will increase if dust is not managed - in this environment in the dry season, heavy vehicles will generate clouds of dust that are visible for several kilometers.

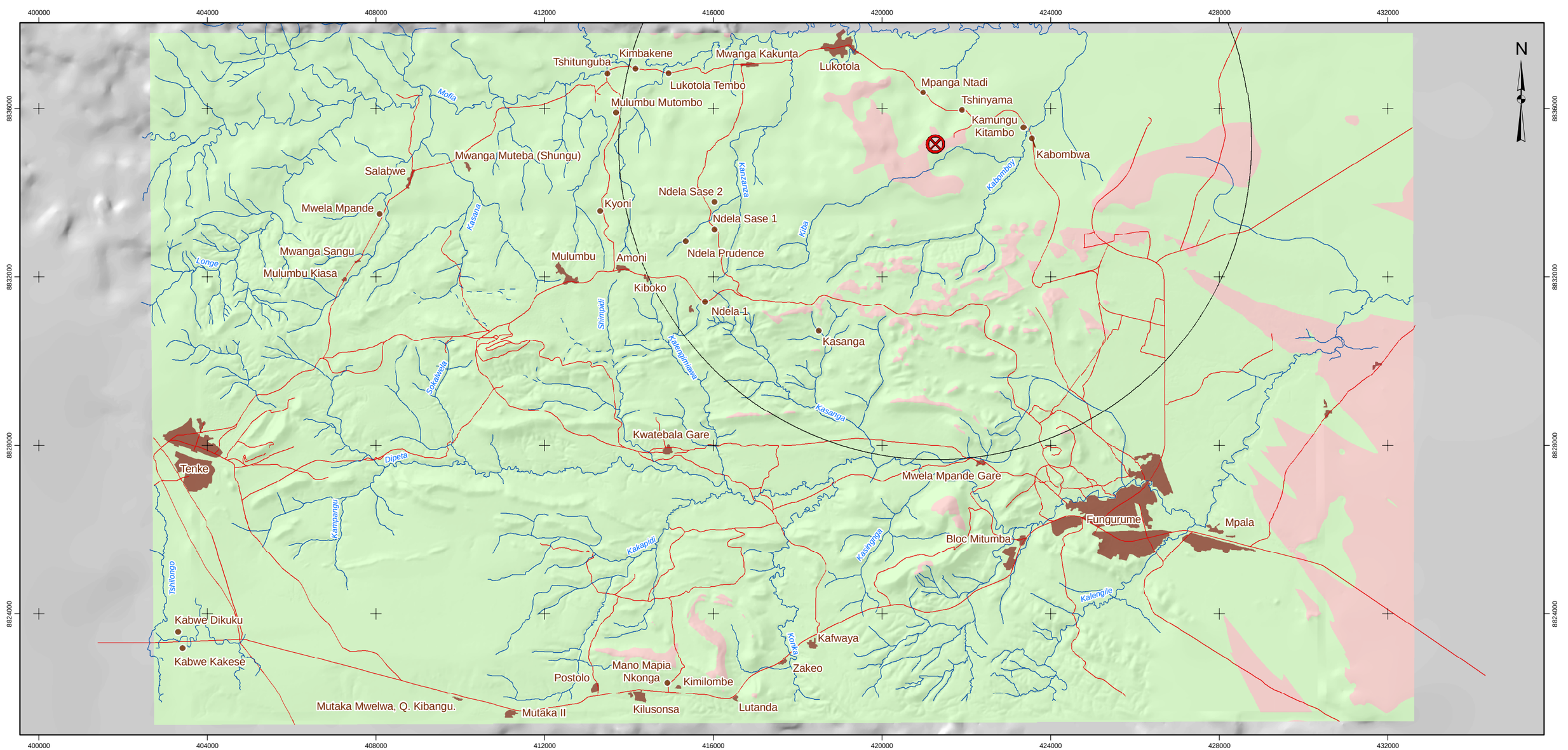
The Mulumbu access road will not be significantly exposed to view from permanent habitation, subject to the inhabitants of the three villages of Mulumbu, Kiboko and Amoni being resettled as planned. Taking into consideration the screening effects of miombo woodland, visual exposure of the local inhabitants to the quarry, power lines and road is expected to be low. This could increase to moderate if many more people settle in the area over time and if the vegetation cover is significantly reduced.

Receptor Sensitivity: The visual impact of the access road, power line and quarry on scenic quality was not raised during the stakeholder consultation. As described in Section C2.5.3.4, stakeholders in the LSA are presently not highly sensitive to visual aesthetic changes, if the changes are due to activities bringing employment to the area. No visually sensitive land uses occur within the viewshed of the facilities that could increase the sensitivities to visual change.

Magnitude of Visual Impact: While the visual intrusion of the roads, power lines and the quarry is expected to be moderate to high, the overall magnitude of impact of the proposed development in terms of key question VA-2 after construction is rated as low, taking into account the screening effects of miombo woodland, the absence of human settlement in the affected area and the low apparent sensitivities to visual aesthetic change. This may change to moderate if these variables undergo significant alteration over time.

Prediction Confidence

There are no known uncertainties that could significantly alter the assessment and the prediction confidence is rated as high.



LÉGENDE / LEGEND

- EMPLACEMENT DU POINT D'OBSERVATION DE LA ZONE DE VISIBILITÉ DE LA CARRIÈRE DE DOLOMIE / DOLOMITE QUARRY VIEWSHED POINT
- VILLAGE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- RÉGION D'INFLUENCE VISUELLE (LA ZONE D'ÉTUDE LOCALE) / ZONE OF VISUAL INFLUENCE (LOCAL STUDY AREA)

ZONE DE VISIBILITÉ DE LA CARRIÈRE DE DOLOMIE / DOLOMITE QUARRY VIEWSHED

- NON VISIBLE / NOT VISIBLE
- VISIBLE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE 1:90000 KILOMÈTRES
SCALE 1:90000 KILOMETERS

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

ZONE DE VISIBILITÉ DE LA CARRIÈRE DE DOLOMIE, 10 MÈTRES AU-DESSUS DU NIVEAU DU SOL / VIEWSHED FROM THE LIMESTONE QUARRY

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	MW	10 Jun. 2006		
GIS / SIG	TN	04 Jan. 2007		
VÉRIFIÉ / CHECK	MR	20 Jul. 2006		
APPROUVÉ / REVIEW	MR	31 Jul. 2006		

FIGURE: C2.5-11

Table C2.5-5 Residual Impact Classification for Key Question VA-2

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question VA-2:	**What effect will the access roads, power lines and limestone quarry have on visual aesthetics?**					
Construction Phase						
negative	low	local	long-term	no	high	low
Operations Phase						
negative	low	local	long-term	no	high	low
Closure Phase						
negative	low	local	long-term	yes	high	low

C2.5.3.6 Key Question VA-3

Key question VA-3 is: What effect will the Goma mine and its associated facilities have on visual aesthetics?

Linkage Evaluation

The visual impacts are linked, in a cause and effect relationship, not only to the changes in topography and geomorphology that will result from the proposed development, but also to the plant design and the air quality management actions practiced (Figure C2.5-3). Dust raised by blasting, materials handling and traveling along unpaved roads will greatly increase the visibility of these activities.

Changes in land use and socio-economic conditions attracting migrants into the area could cause large-scale changes in visual aesthetics as a result of the need to clear Miombo woodland for agriculture. Disturbance of stream courses and water quality could also have visual aesthetic effects.

In the absence of important heritage issues there are no forward linkages from visual impact to other topic areas.

Assessment Methods

Visual intrusion was measured in accordance with the same structured rating scale from high to low (in a negative direction) that was set out in Section C2.5.3.4. Visual simulations were prepared which show the appearance of the project in the landscape from the most important receptors. The rating scale in Table C2.5-3 was then applied, using the simulation as a measure of change.

Visibility of the mining was measured using GIS viewshed analysis from the highest point on the Goma hills. *Visual exposure* was determined from the view

shed and from the ESIA mapping of land use within the 7.5 kilometer cut off zone, beyond which visual impacts of an industrial facility in this type of terrain become insignificant.

Receptor sensitivity was determined from a knowledge of land use within the study area and from the results of the stakeholder consultation during the course of the ESIA, in which issues raised by members of the public and the government were captured.

Mitigation

The following mitigation measures will be employed to minimize impacts of mining on visual aesthetics:

- **Vegetation Screening:** As much of the existing vegetation as possible will be left intact during construction of the mine for its screening effect in addition to its aesthetic value. The miombo woodland will be a highly effective screen of the mining. Fast-growing indigenous trees will be planted in a dense screen along the boundary of the town of Tenke, subject to agreement with local stakeholders. This simple but effective means of visual screening will be undertaken during the construction phase of the Kwatebala mine, giving the trees the chance to grow to maturity before mining at Goma and Fwaulu starts. The cooperation of the local authorities and population in planting and maintaining the trees will be necessary and measures to encourage this will need to be investigated.

Results

Visual simulations comparing the current and future views from Tenke towards Goma hill are shown in Figure C2.5-12. The viewshed modeling for the Goma hills is shown in Figure C2.5-13.

Impact Analysis

Visual Intrusion: The magnitude of change in the landscape that will be caused by the mining operation will be high, with intensive alteration of landscape characteristics over a moderately large area. The visual quality of the existing landscape is high and the introduction of the mining facility will contrast significantly with the existing patterns of land use and natural habitats.

R:\CAD\2005\1322-EA\1334\05-1334-035\6500\6520\JUNE29-2006\Fig C2.5-12_Current-Future Views-Goma Hills from Tenke.dwg Jul 19, 2006 - 2:58pm

Monts Goma, vues depuis le côté est de Tenke / Goma Hills viewed from the eastern side of Tenke

Monts Goma en exploitation vues à partir de l'est, noter les haldes de stériles exposées, vues depuis le côté est de Tenke (simulation visuelle) / Goma Hills mined from the east, showing waste rock dump exposed, viewed from the eastern side of Tenke (visual simulation)

PROJECT/PROJET

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITLE/TITRE

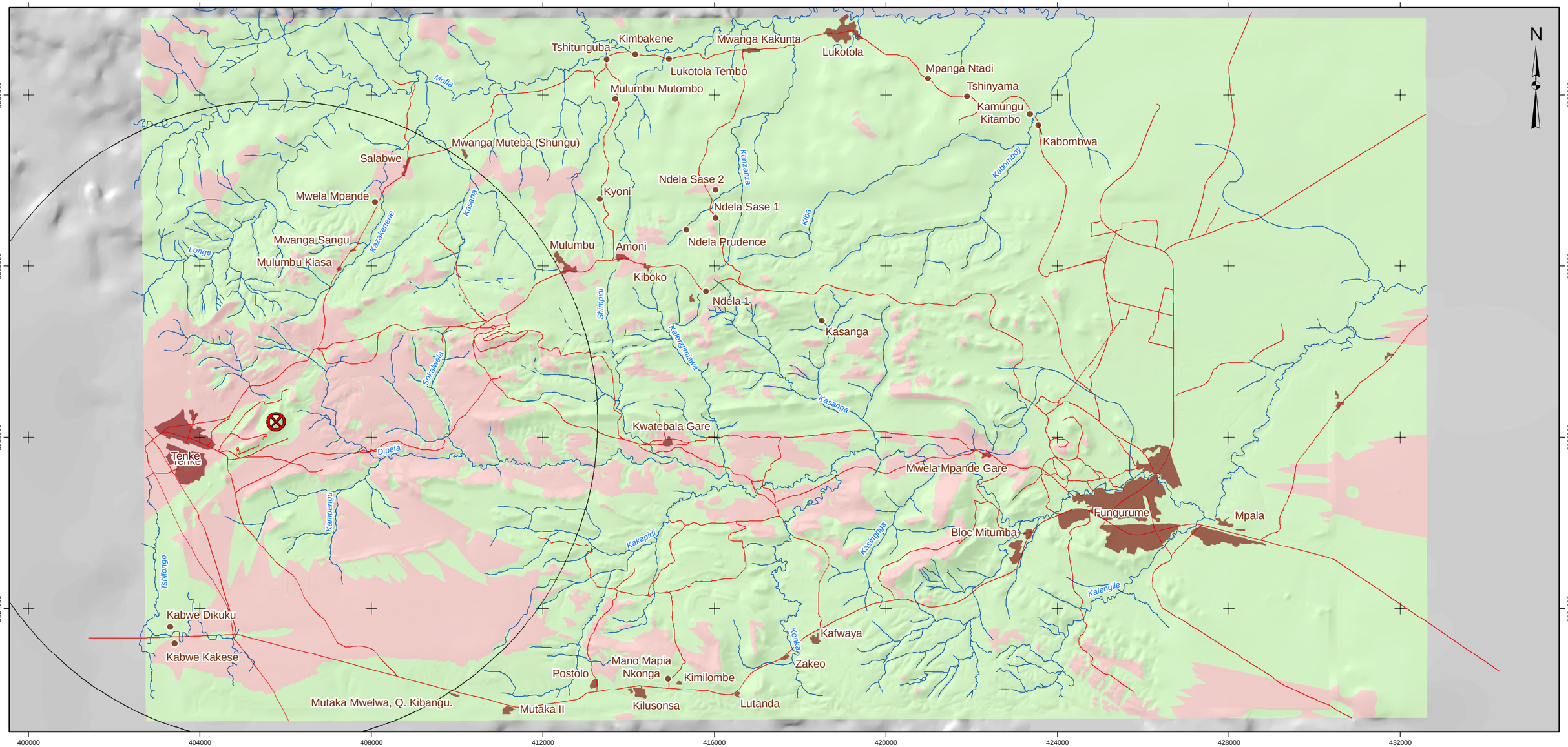
VUES ACTUELLE ET FUTURE DES MONTS GOMA DEPUIS TENKE
CURRENT AND FUTURE VIEWS OF THE GOMA HILLS FROM TENKE

Golder Associates
Calgary, Alberta

PROJECT/PROJET	05-1334-035	
DESIGN/DESSIN	MR	30/06/06
CADD/CAD	SWD	19/07/06
CHECK/VERIFIÉ	MR	19/07/06
REVIEW/APPROUVÉ		

FILE No. Goma Hills-Tenke
SCALE/ECHELLE AS SHOWN REV. 0

FIGURE: C2.5-12



LÉGENDE / LEGEND

- EMPLACEMENT DU POINT D'OBSERVATION DE LA ZONE DE VISIBILITÉ DES MONTS GOMA / GOMA HILLS VIEWSHED POINT
- VILLAGE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- RÉGION D'INFLUENCE VISUELLE (LA ZONE D'ÉTUDE LOCALE) / ZONE OF VISUAL INFLUENCE (LOCAL STUDY AREA)

ZONE DE VISIBILITÉ DES MONTS GOMA / GOMA HILLS VIEWSHED

- NON VISIBLE / NOT VISIBLE
- VISIBLE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE / SCALE 1:90000 / 1:90000 KILOMÈTRES / KILOMETERS

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

ZONE DE VISIBILITÉ DU SOMMET DES MONTS GOMA / VIEWSHED OF THE HIGHEST ELEVATION IN THE GOMA HILLS

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035		ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	MW	10 Jun. 2006	
GIS / SIG	TN	04 Jan. 2007	
VÉRIFIÉ / CHECK	MR	20 Jul. 2006	
APPROUVÉ / REVIEW	MR	31 Jul. 2006	

FIGURE: C2.5-13

Visibility and Visual Exposure: Like Kwatebala, Goma is a high point in the landscape. Because of its location at the western end of the Dipeta River valley, it is visible along the Dipeta River to the east for considerable distances, with (theoretical) views extending all the way to Mwela Mpande some 17 kilometers away. Views to the north are restricted by intervening terrain. Immediately to the east, the hill is very visible and forms a landmark from Tenke. It is also visible from a large area to the south on the main Kolwezi Road (Figure C2.5-13).

The population in Tenke (11,000 people) will be exposed to views of mining at Goma. The nearest point on the Goma hills is less than 700 meters from the eastern edge of the town of Tenke. This exposure would gradually reduce as the hill is mined away and the mining continues below natural ground level, leaving the waste rock facility visible.

Salabwe (at a distance of about seven kilometers) and the tiny settlements of Mwanga Sangu and Mulumbu Kiasa are also (theoretically) exposed to views of the Goma hills. In practice, these villages are likely to be screened from views of Goma by miombo woodland. Other areas of visual exposure include a section of the National Road Number 1 to Kolwezi which is presently underutilized because of its very poor condition. If the road is upgraded and traffic volumes increases, the mining will be visible to road users in the final section of the route between Fungurume and Tenke.

The magnitude of visual exposure of the population at Tenke to the mining activities on the Goma hills is expected to be high, assuming mining from east to west. Exposure of other communities to views of the mine is expected to be low.

Receptor Sensitivity: The discussion in Section C2.5.3.4 on visual sensitivity with respect to mining of the Kwatebala Hill applies, in general, to mining of the Goma hills as well. If Goma were to be mined at present, public concern for scenic quality would be rated as low. Due to the proximity of Tenke to the mining area and the probability that local residents will become more concerned about scenic quality as their material well-being improves, this rating may escalate to moderate by the year 2015, when mining at Goma is scheduled to start.

Magnitude of Visual Impact: The impact of the proposed development in terms of key question VA-3 is rated as high due to the proximity of Tenke (Table C2.5-6). Effects at closure are expected to be moderate due to reclamation of the waste rock stockpile.

Table C2.5-6 Residual Impact Classification for Key Question VA-3

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question VA-3: What effect will the Goma mine and its associated facilities have on visual aesthetics?						
Construction Phase						
negative	high	local	long-term	no	high	high
Operations Phase						
negative	high	local	long-term	no	high	high
Closure Phase						
negative	moderate	local	long-term	yes	high	moderate

Prediction Confidence

TFM proposes to start mining Goma in 2017 and it possible that there will be changes in surrounding land use before then, the exact nature of which are not known at this time. There is also very limited mine planning information available. Accordingly, the prediction confidence for the proposed mining operations at Goma is moderate.

Monitoring

Monitoring requirements will be as proposed for mining of Kwatebala as discussed in Section C2.5.3.4.

C2.5.3.7 Key Question VA-4

Key question VA-4 is: How can the project influence the quality of the visual resource to have a long-term positive effect?

Assessment Methods

The assessment methods for this question were qualitative, using professional judgment and experience. Key questions VA-1 to VA-3 concern the assessment and management of negative visual effects caused by the construction and operation of the development, while key question VA-4 emphasizes the potential for long-term sustainable benefits in visual quality.

Mitigation

The post-closure landscape of the TFM project will be developed to meet the criteria set out in the project reclamation and closure plan (Section D5), and will include measures to ensure that an ecologically stable environment remains,

which is not harmful to surrounding inhabitants and which does not aesthetically blight surrounding areas. Proposals to leave behind an aesthetically acceptable environment include measures to rehabilitate disturbed areas, including the slopes of tailings storage facilities, with indigenous species.

TFM will commit to a management program for copper-cobalt plant species (Section C3.1) and for conservation of a portion of the unique topography/geomorphology that occurs in the concession area (Section C2.1). It will also be important to develop a land use management plan, negotiated with the local authority and local communities (Section C3.1).

Results

The project will cause permanent changes to landforms in the LSA. It is likely that some of these changes will be useful, particularly where very flat landscapes have been created as a result of benching for the plant. These spaces will be at a premium in the hilly countryside of the project area and will probably be put to continued industrial use, rural settlement or even agriculture.

The pit lakes that will be associated with the final landform of the mining area at Kwatebala, Goma and Fwaula will have potential for community use, if safe access to the water level is provided. Subject to an appropriate rehabilitation strategy, these enclosed environments can be converted into places which are aesthetically pleasing and which have a long-term and sustainable use.

It is probable that the improved economic circumstances that will prevail in the local communities as a result of the project will cause a significant and beneficial change in the appearance of the local rural villages and towns. With more money circulating in the economy, there will be improved living conditions, people will upgrade and paint their houses and the overall appearance of the villages close to the project will change to reflect a community that is better able to sustain itself. Successful development interventions in the local area will therefore play an important role in visual quality.

Impact Analysis

The positive long-term visual aesthetic impacts that are forecast will be of moderate magnitude and will reach over half the community (Table C2.5-7). The probability of success is medium and the overall sustainability consequence is medium. The creation of a conservation area would have moderate visual consequence at a local scale, which could escalate to high if the use of the area is promoted for walking trails or other public uses. The sustainability consequence is rated as medium.

Table C2.5-7 Residual Impact Classification for Key Question VA-4

Areas of Visual Interest	Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key Question VA-4: How can the project influence the quality of the visual resource to have a long-term positive effect?					
Reclamation and mine closure and upgrading of villages due to improved socio-economic conditions					
mining areas	moderate	half the community	long-term	medium	moderate
local villages	moderate	half the community	long-term	medium	moderate
Creation of a conservation area					
local area	moderate	few	long-term	high	moderate

Prediction Confidence

The confidence in the predictions for aesthetic benefits associated with the closure of the mine are moderate. For the aesthetic benefits that will result from the evolving socio-economic development strategy in the RSA, the prediction confidence is low, since benefits will depend on the success of this long-term program.

Monitoring

Monitoring of the rehabilitation of the mining and plant processing areas will be covered under the reclamation and closure plan (Section D5). No specific aesthetic monitoring is proposed. No monitoring is proposed for positive changes in visual aesthetics in settled areas as a result of improved socio-economic conditions or as a result of the creation of a conservation area.

C2.5.4 Cumulative Effects Assessment

Linkage Evaluation

Should the TFM project be expanded from 115,000 tonnes per year production to 400,000 tonnes per year, the physical extent of the mining, processing plant, waste rock and tailings facilities would expand considerably.

Assessment Methods

Detailed plans for the increased levels of production to expand to 400,000 tonnes per year are not yet available. Consequently, it is uncertain whether there will be a significant change in the location of some of the facilities and where this change would occur. In the absence of this information, the general concept of the expansion was reviewed in the context of known aesthetic baseline conditions. Professional experience was used to assess the changes, specifically

in relation to the additional mining required, the expanded processing capacity and the requirements for a four-fold increase in capacity in the waste rock stockpiles and tailings disposal facility. The principles developed for closure plans and other project goals to mitigate negative effects were considered in the assessment of impacts.

Mitigation

The type of mitigation proposed for impacts VA-1, VA-2 and VA-3 would apply to the expanded facility. If additional tailings storage and waste rock facilities were required, similar methods would be necessary to mitigate the impacts. Dust management would become an issue which required particular attention, taking into consideration the increase in traffic on unsurfaced roads.

Results

The effects of the 400,000 tonne per year case on visual aesthetics would be greater in magnitude than the corresponding 115,000 tonne per year case, but the types of impacts would remain the same. It may be expected that the waste rock and tailings facilities that are proposed for the 115,000 tonne per year case would be expanded as much as possible at the existing sites within the constraints imposed by terrain and thereafter new sites would have to be developed. Approximately four times the land that would be needed for the base case would be affected by the expansion. It is unlikely that sites could be found that have less visibility and visual exposure than the existing sites, so it is anticipated that the numbers of people affected by views of the sites will increase by at least four times and probably by more. Development of the Fungurume deposit would raise issues similar to those affecting the Goma deposit, because of the proximity of the town to the working areas on the mine.

Impact Analysis

For the cumulative development case, impacts will occur across a much greater area in the LSA and, in addition, in localities outside of the LSA, such as Fungurume. Visual exposure of mining and mining infrastructure is expected to increase significantly above the base case, probably by more than the proportionate four times enlargement. The impacts are predicted to be moderate in magnitude (following all mitigation), regional in geographic extent, long-term in duration and of high frequency. The impacts will be partly reversible by means of rehabilitation. The environmental consequence of these effects will be high for construction and operation and moderate to high after closure (Table C2.5-8).

Table C2.5-8 Residual Impact Classification for Key Question VA-5

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question VA-5: What cumulative effect will the project have on visual aesthetics?						
Construction Phase						
negative	moderate	regional	long-term	no	high	high
Operations Phase						
negative	moderate	regional	long-term	no	high	high
Closure Phase						
negative	low to moderate	regional	long-term	yes	high	moderate to high

Prediction Confidence

While the visual aesthetics baseline is well understood, the absence of detailed information about the 400,000 tonnes per year case limits the prediction confidence of the assessment of the cumulative effects of the development to low.

C2.5.5 Conclusions

Impacts are evaluated separately for the Kwatebala mine, the limestone quarry and access road/power line, and the Goma mine as well as accumulate effects, in Table C2.5-9.

The TFM project will cause visual aesthetic impacts of low to moderate magnitude and low to moderate environmental consequence. The facility will be intrusive in a predominantly natural environment, but the effect of this will be minimized by the limited visibility of most of the mining, plant and infrastructure, the absence of large populations exposed to the views and the lack of sensitivity of those viewers who will see the developments to visual aesthetics issues.

Under the cumulative development case, the project expansion from 115,000 tonnes per year to 400,000 tonnes per year could significantly increase the visual exposure of local people to mining and processing. This would increase the magnitude of the impact and would raise the environmental consequence to high for construction and operation, and moderate to high for closure (Table C2.5-9).

Table C2.5-9 Summary of Residual Effects for Visual Aesthetics

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question VA-2: What effect will the access roads, power lines and quarry have on visual aesthetics?						
Construction Phase						
negative	low	local	long-term	no	high	low
Operations Phase						
negative	low	local	long-term	no	high	low
Closure Phase						
negative	low	local	long-term	yes	high	low
Key Question VA-3: What effect will the Goma mine and its associated facilities have on visual aesthetics?						
Construction Phase						
negative	high	local	long-term	no	high	high
Operations Phase						
negative	high	local	long-term	no	high	high
Closure Phase						
negative	moderate	local	long-term	yes	high	moderate
Key Question VA-5: What cumulative effect will the project have on visual aesthetics?						
Construction Phase						
negative	moderate	regional	long-term	no	high	high
Operations Phase						
negative	moderate	regional	long-term	no	high	high
Closure Phase						
negative	low to moderate	regional	long-term	yes	high	moderate to high

Reclamation and closure, and upgrading of villages due to improved socio-economic conditions, will result in a medium sustainability consequence (Table C2.5-7). Similarly, creation of a conservation area will lead to a medium sustainability consequence.

C2.6 MAJOR HAZARDS

C2.6.1 Introduction

This section presents the assessment of major project hazards for the public and the environment, according to the Tenke Fungurume Mining (TFM) project terms of reference (Section E8). Major hazards include the natural risks imposed on the mine operations due to extreme meteorological or seismic events. Additionally, accidents or malfunctions in the processing plant operations may impact both on and off-site members of public and the environment. Rail and road transportation accidents may also spill hazardous materials both on and off the TFM project site. Transportation activities also have the potential to cause injuries or fatalities from accidental collisions.

The information presented includes details on:

- Potential issues regarding major hazards.
- Project activities that may increase the risk of impacts to the public and environment.
- Mitigation measures incorporated in the project design for these impacts.

This section is organized as follows:

- Section C2.6.2 describes the study areas.
- Section C2.6.3 discusses the impact assessment and sustainability approach and results.
- Section C2.6.4 provides the cumulative effects assessment.
- Section C2.6.5 discusses the conclusions of the assessment.

Baseline information concerning major hazards has been provided in Section B2.6.

A glossary of terms and acronyms used in this section is provided at the back of this volume.

C2.6.2 Study Areas

The study areas for the major hazards impact assessment are the same as those for the baseline described in Section B2.6. No formal regional or local study areas were used.

The natural risks study areas vary based on the particular risk being discussed. Although the area of focus is the immediate vicinity of the project, data from a much wider area has been used to better assess risks associated with climatic and seismic events. The processing plant study area is adjacent to the processing plant described in the project description (see Section A4.4). Transportation corridors for both on site and off site transport define the transportation study areas as described in the project description (see Section A4.2).

C2.6.3 Impact Assessment

C2.6.3.1 Issue Scoping

The key project issues relating to major hazards are the potential impacts to the public and environment due to:

- Natural hazards including extreme seismic, meteorological and geotechnical events.
- Processing plant hazards from accidents or malfunctions.
- Mining operations hazards from accidents or malfunctions.
- Transportation hazards from accidental spills or collisions.

Issues relating to major hazards noted during the public consultation process (Section A6) include a number of concerns related to increases in traffic. These include:

- Concerns regarding increased dust generated by traffic, particularly during the dry season, and resulting potential impacts on women, children and food vendors who frequently use roadways both for transportation and as areas of commercial activity.
- Concerns regarding potential accidents as result of increased traffic along roads near and through the concession.

Finally, there were public concerns regarding potentially dangerous open culverts constructed by TFM in the concession, and the need to mitigate public risk.

Mitigation measures discussed included dust suppression, which is addressed in Section C2.8, air quality. In addition, several safety measures will be implemented about safe driving practices for TFM staff and contractors, including speed limits, drivers' education, vehicle scheduling, and vehicle maintenance and, most importantly, public education. These measures will reduce the potential for accidents along roadways within the concession. Mitigation of collision risks is addressed in Section C4, social impact and in this section.

C2.6.3.2 Key Questions and Indicators

The key question for major hazards is presented in Table C2.6-1. A sustainability assessment key question does not apply to major hazards (Section C.2.6.3.5).

Table C2.6-1 Key Question for Major Hazards

Impact Assessment
Key question TG-1: What effect will major hazards associated with the project have on the public and environment?

Indicators for major hazards include the engineering design basis for facilities and the operational control of the mine, plant and transportation activities. These indicators are discussed in this section and they relate to risks of major hazards occurring. The indicators are also reflected in the Global Reporting Initiative (GRI) Mining and Metals Supplement (GRI 2005). The sustainability benefits relative to natural hazard management are included in the mitigation measures proposed. There is no need for a separate key question related to long-term positive effects for the sustainability assessment. The linkage between natural hazards and other disciplines is further discussed in Section C2.6.3.5.

C2.6.3.3 Assessment Criteria

The criterion for assessing major hazards was developed in a project risk assessment framework beginning with the project concept phase and continuing throughout the mine life cycle. At the project concept phase, all project risks were generally assessed according to the complete range of project consequence categories, including:

- Commercial.
- Social.
- Technological.

- Logistical.
- Environmental.
- Operational.
- Economical.

Project risks were identified according to:

- Hazard scenario issues.
- Contributing factors.
- Consequences.
- Control strengths and weaknesses.
- Risk estimate.
- Treatment actions.

Assessment criteria were defined in terms of a project risk matrix with five categories of likelihood and severity of consequences. A risk rating from low to significant was defined through different levels in the risk matrix. The project risk matrix, with the public safety and environment consequence categories relevant to the TFM project's environmental and social impact assessment (ESIA) is presented in Table C2.6-2.

As shown in the project risk matrix, the assessment criteria for major hazards are different from those used in other sections of the ESIA. Risk criteria were used to evaluate residual impacts (following implementation of mitigation measures) based on the frequency that a specific public or environmental consequence could occur. Assessment criteria for the other ESIA sections were not defined as risks but were ranked according to a list of criteria. However, the environmental consequences in both approaches are similar.

The TFM project's overall concept risk assessment includes general risk scenarios for all project impact categories, including those for major hazards (as described in Section C2.6.3.1, on issues scoping). As the project was developed to support the ESIA, detailed hazard scenarios were identified along with mitigation and monitoring measures. These hazard scenarios provided the basis for the major hazards impact assessment. Risk criteria shown in the project risk matrix were qualitatively applied. More detailed risk assessments will be completed when the project progresses to detailed engineering, construction and operation phases.

Table C2.6-2 ESIA Risk Matrix

		CONSEQUENCE SEVERITY				
CATEGORY		**1) Very Low**	**2) Low**	**3) Moderate**	**4) High**	**5) Very High**
Public Safety		no physical effects	medical treatment	irreversible disability	fatality	multiple fatalities
Environment		negligible physical or biological effects	short-term local effects	medium-term regional effects	long-term regional effects	long-term ecosystem effects
LIKELIHOOD	A) probable					
	B) likely					
	C) possible					
	D) unlikely					
	E) rare					

Risk Rating	
significant	
high	
moderate	
low	

C2.6.3.4 Key Question TG-1

Key question TG-1 is: What effect will major hazards associated with the project have on the public and environment?

Assessment Methods

Natural hazards were identified during the preliminary engineering for the mine. This was done to develop a design and operating basis to minimize seismic risks, extreme meteorological risks and geotechnical risks. Baseline data described in Section B2 were used to determine applicable designs to protect against all natural hazards in the region.

Processing plant hazards were identified through a formal Preliminary Process Hazard Identification Study (HAZID) of the engineering drawings (MinProc 2007). The processing plant was divided into units to be studied individually and then was studied as a complete processing plant. Events ranging from fire and explosions to pollution were studied to identify specific hazard scenarios including causes, consequences, safeguards and recommendations to minimize potential risks. These hazard scenarios covered a range of issues including worker safety, process technology, operating efficiency and environmental releases. Those hazard scenarios impacting the environment and public safety were assessed as major hazards for the ESIA.

Mining hazards were also identified during preliminary engineering in order to develop a design and operating basis to minimize public and environmental risks. Site investigations were done to support design criteria.

Transportation hazards were identified during development of the feasibility study for transport and logistics (MinProc 2007). The volume of reagents and fuel to supply the mine operations were studied along with the product exports to determine rail and truck requirements. Transport routes were studied along with material properties, packaging and exposure volumes to assess spill hazards and risk mitigation measures. In addition, transport collision hazards, both on-and-off site, were assessed. Major internationally recognized protected areas located along transport routes with ports were reviewed and supplemental risk mitigation risk proposed for these areas.

Mitigation

Risk mitigation measures will be implemented for all potential major hazard scenarios. Designs for the processing plant, mine site and tailings storage facility are developed from international standards to minimize risks to within acceptable

levels for the public and environment. The transportation program incorporates mitigation measures to minimize risks from accidental spills and collisions.

Measures to minimize natural risks for the mine including the tailings storage facility, waste rock facilities, ore stockpiles and return water dam include:

- Geotechnical testing of tailings, fill, waste overburden and foundation materials.
- Design for placing the waste rock facility against the north embankment of the tailings storage facility.
- Tailings storage facility (TSF) containment designed for extreme storm and wet year's water cycle.
- Spillway for the closure phase of the TSF.
- Slope stability analyses.
- International standards for acceptable factors of safety.
- Design earthquake ground motions and deformations.
- Conservative selection of design storm.
- Site-wide storm water management including drainage from dumps.
- Embankment freeboard.
- Procedures preventing ponding (water build-up) near the crest of waste rock facilities.
- Installation of instrumentation to monitor stability of dams.
- Regular inspections, maintenance and monitoring.
- Only reputable transport firms will be hired, and the safety records of these firms will be reviewed.
- The project will conduct audits of transport company safety performance and will have a mechanism in place to investigate spills, if any occur.
- In protected areas:
  - Audits will be performed to ensure transport firms are not impacting such areas with spills or other accidents.
  - Traffic will generally be developed during day light driving conditions to minimize risk of accidents and especially collisions with wildlife.
  - Reduced speed limits will be observed on a case by case basis.

Measures to minimize natural risks for the processing plant include:

- Safe shut-down design.
- Tank, vessel and piping design for seismic loads.
- Drainage ditch design for storm events.
- Tank and vessel design for wind loads.
- Foundation design for geotechnical conditions and extreme seismic events.
- Foundations and site drainage ditch design for geotechnical conditions and extreme flooding events.

Measures to minimize processing plant hazards include:

- Interlocks automatically linking equipment controllers to prevent releases due to power loss, equipment failure or operator error.
- Drains to containment areas in case of liquid releases.
- Emergency power for critical equipment.
- Safe designs allowing for internal storage in case of pump failure.
- Standby pumps.
- Extensive monitoring of process variables for control.
- Fire safeguards including hazardous classification, non-flammable construction material, fire walls, high-temperature flash point diluting (diluting agent), low-velocity flow rates and safety instrumentation.
- Process risk analysis to minimize risk of accidental sulfur dioxide and sulfur trioxide releases from the sulfuric acid plant impacting the public and environment.
- Site-wide storm and wash water containment.
- Emergency response procedures for local communities.

Measures to minimize mining hazards associated with the ore and soil stockpiles and the waste rock facilities (not resulting from a natural hazard) include:

- Geotechnical testing of waste overburden, ore and foundation materials.
- Physical and chemical stability of waste rock facilities.
- Design for slope stability.
- Regular inspections, maintenance and monitoring.

Measures to minimize transportation hazards associated with accidental spills and collisions include:

- Rail and road traffic management considerations to minimize public and environmental exposure on and off site.
- Transportation risk assessment for reagents, fuel and products before operations start.
- When needed, use of convoys, escorts and travel restrictions (e.g., vehicle speed and daylight driving).
- Packaging cargo to limit spill potential and severity.
- Road maintenance monitoring.
- Equipment quality, maintenance and real-time tracking.
- Driver training, procedures and experience.
- Emergency response procedures.
- On-site road design.

Results

Natural Hazards

A natural hazard is a naturally occurring event that could lead to potential failure of project facilities that would impact the public or the environment. Three principal natural hazards are identified as:

- Seismic.
- Extreme meteorological events.
- Geotechnical events.

The issues associated with each principal natural hazard are summarized later in this section. All the issues identified from stakeholder consultations were also included in these hazard scenarios. Reference is made to the map presented in Figure C2.6-1 (from the tailings engineering assessment) to identify facilities that may potentially be impacted by natural hazards.

1 0 1

ÉCHELLE 1:30000 KILOMÈTRES
SCALE 1:30000 KILOMETERS

LÉGENDE / LEGEND

- COURBE DE NIVEAU (INTERVALLE DE 10 METRES) / CONTOUR (10 METER INTERVAL)
- CHEMINS DE ROULAGE/ HAUL ROAD
- ROUTE / ROAD
- RETENUE D'EAU / DAM
- FOSSE / MINE PIT
- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- EAU / WATER

RÉFÉRENCE / REFERENCE

Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

INSTALLATIONS DE TFM POTENTIELLEMENT EXPOSÉES AUX RISQUES NATURELLES / TFM FACILITIES POTENTIALLY AT RISK TO NATURAL HAZARDS

Golder Associates
Calgary, Alberta

N° projet / project no. 05-1334-035.9300		Échelle telle qu'indiquée / Scale as Shown	REV. 0
DESSIN / DESIGN	BG	04 Jun. 2006	
SIG / GIS	TN	04 Jan. 2007	
VÉRIFIÉ / CHECK	MR	20 Oct. 2006	
APPROUVÉ / REVIEW	MR	20 Oct. 2006	

FIGURE: C2.6-1

Project I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\mxd\Tenke_ESIA\Volume_C\FigureC2.6-1_TFM_facilities.mxd - Plot I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\pdf\Tenke_ESIA\Volume_C\FigureC2.6-1_TFM_facilities.pdf

Site-specific seismic hazards were studied (Golder 2006a) to develop design values for the peak horizontal ground acceleration based on a maximum credible earthquake. Results are summarized in the baseline study presented in Section B2.6. Ground motions from an earthquake could potentially cause the following hazard scenarios:

- A landslide into the tailings storage facility or return water pond which could cause water to rise above the top (overtopping) or breaching of the embankments.
- Liquefaction of the embankments and/or foundations which could cause water to spill over or breach the embankments.
- Liquefaction of waste rock facilities, stockpiles and excavated slopes which could cause a flow slide (e.g., mud slide).
- A power failure causing a processing plant shutdown causing releases into the environment.
- Damage to processing plant structures causing releases into the environment.
- Rupture of containment facilities (e.g., process tanks) causing releases into the environment.
- Damage to chemical stockpiles, (e.g., sulfur) causing releases into the environment.

The seismic criteria used for engineering design was presented in the project description (see Section A4.6.1.2). An operating basis earthquake of 0.12 gravity units lateral acceleration was designed for. The engineering design used will reduce the risk of such consequences for all events up to the maximum credible earthquake. Extensive geotechnical investigations are being conducted to support the engineering designs. The principal embankment is located to the north of the tailings storage facility and an additional risk mitigation measure in the proposed design is the placement of the waste rock facility against this embankment. Additional engineering and operational risk mitigation measures are described earlier in this section.

The Dam Break Assessment (the likelihood and consequences of an instability of one or more of the tailings storage facility perimeter embankments, even after an occurrence of the maximum credible earthquake) determined that the risk of embankment failure is negligible (see Section 9.10.5.6 of MinProc 2007; see also Section 8.4 of MinProc 2007 for design standards).

Extreme meteorological events include high-intensity rainfall, causing flash floods and erosion, and high wind events. Baseline data presented in

Section B2.6 were used to develop engineering design storm events. Extreme storm events could potentially cause the following hazard scenarios:

- A landslide into the tailings storage facility, return water pond or evaporation pond which could cause overtopping or breaching of the embankments.
- Erosion and failure of the embankments which could cause release of water or tailings to the environment.
- The creation of a large wave from high winds that could overtop or breach the embankments.
- Concentrated flow of water over the outer slope of the waste rock facilities could cause erosion and a localized flow of saturated waste rock material.
- Ponding of water next to the outer rim of the waste rock facility could cause a localized slide of material along a saturated slippage face.
- Overloading of storm water control ditches, berms, catchments, and/or the access road which could cause uncontrolled discharge of high-sediment storm waters and loss of infrastructure (i.e., loss of pumps, piping and power lines that may be required to control the risk).
- Flooding could cause overloading of the containment areas in the processing plant and release chemicals to the environment.

Storm event criteria for engineering design is presented in the TFM project description (see Section A.4.5 and Appendix E9). The engineering design used will reduce the erosion and overtopping risks for all events less than these extreme events. The design storm events that have been used are:

- 1 in 100 year wet season, or normal wet season plus occurrence of a probable maximum flood.
- All closure design work: one in 1,000 year wet annual rainfall will be contained; in events exceeding this, storm water will be drained through a permanent spillway channel.

As described above, the principal tailings storage facility embankment will be buttressed (supported) with a waste rock facility which will also minimize risks from extreme storms. Additional engineering and operational risk mitigation measures were described earlier in this section.

The feasibility report (MinProc 2007) notes that the likelihood of an embankment overtopping due to a severe storm event is less than one in 100,000 or below the

risk matrix criteria (see Section 9.1.0.5.6 on dam break assessment). The consequences are also estimated to be low.

Unforeseen geotechnical conditions could occur as an isolated event or along with a seismic or extreme storm event. These events could potentially cause the following hazard scenarios:

- A landslide into the tailings storage facility or return water pond which could cause overtopping or breaching of the embankments.
- A landslide along the embankments due to poor foundation conditions that could cause overtopping or breaching of the embankments.
- A landslide at the waste rock facilities or excavated slopes due to poor foundation conditions which could cause a flow slide.

Site investigation and geotechnical testing will minimize the potential for these risks. Engineering design criteria for waste rock facilities in terms of heights and slopes were presented in the TFM project description (see Section A.4.4). Additional engineering and operational risk mitigation measures are described earlier in this section.

A hazard assessment has not yet been carried out for the eastern tailings facility located north of Fungurume (Figure C1.6-1), which may be required toward the end of the 20-year mine life. Natural hazards in relation to this facility will be assessed prior to construction.

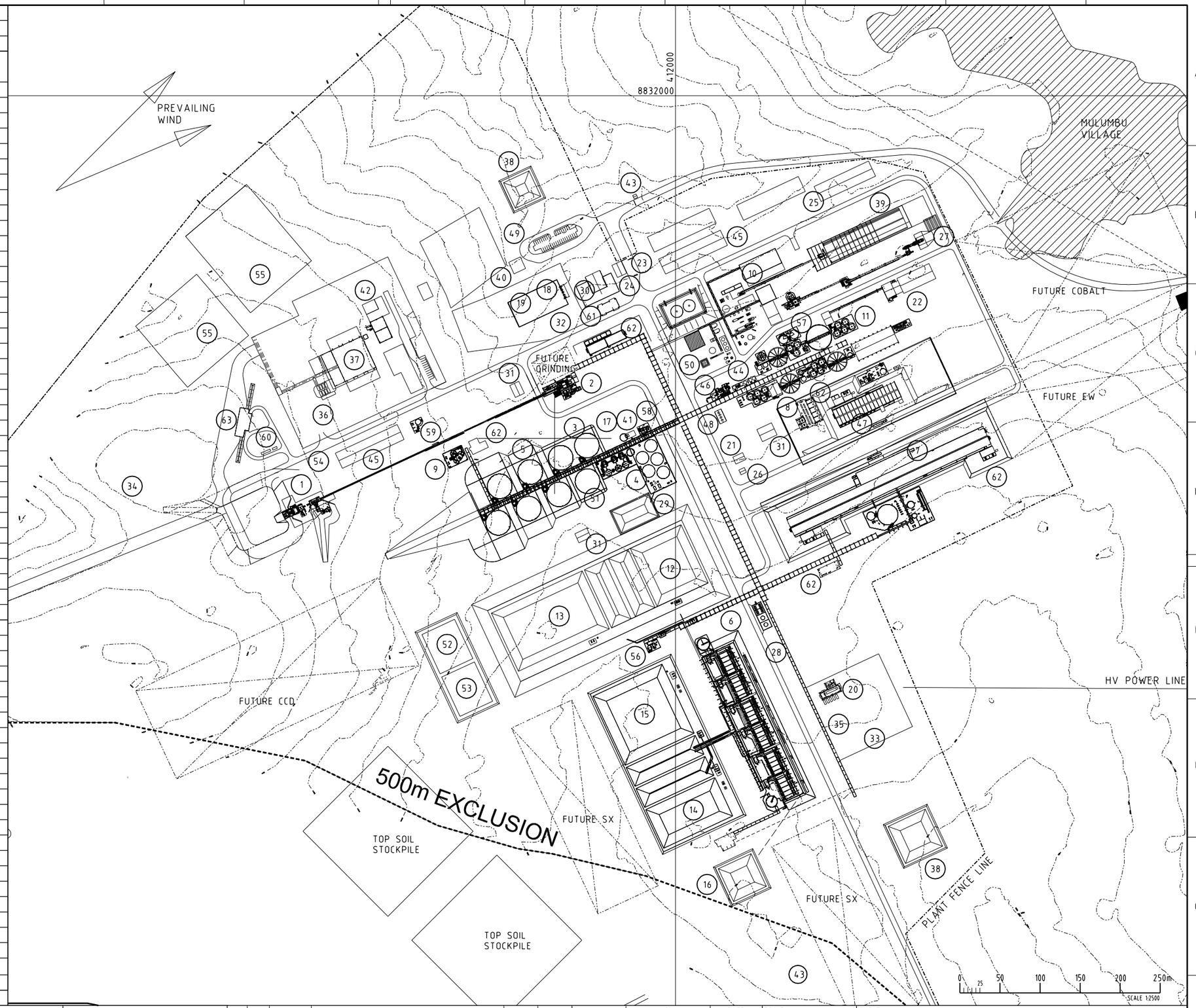
Processing Plant Hazards

Reference is made to the processing plant units described in the layout presented in Figure C2.6-2 (from Figure A4.4-3) to identify locations of potential major hazards.

Hazards associated with the processing plant facilities were identified through a formal HAZID study, as described in the assessment methods section. The following deviations have been considered for individual processing plant units and the complete processing plant site:

- Loss of operations/interruption.
- Explosion.
- Fire.
- Harmful/noxious materials.
- Critical equipment.
- Noise.

NUMBER	DESCRIPTION		AREA
1	CRUSHING & EMERG. RECLAIM	CONSASSAGE ET ALIMENTATION D'URGENCE EN MINERAI	0010
2	GRINDING	BROYAGE	0020
3	LEACH FEED THICKENING	EPAISSISSEMENT DE LA SOLUTION LIXIVIANTE	0030
4	LEACHING	LIXIVIATION	
5	COUNTER CURRENT DECANTATION	DECANTATION A CONTRE COURANT	0040
6	SOLVENT EXTRACTION	EXTRACTION PAR SOLVANT	0060
7	COPPER ELECTROWINNING	ELECTRO-OBTENTION DU CUIVRE	0070
8	COBALT RECOVERY PLANT	USINE DE RECUPERATION DU COBALT	0080
9	NEUTRALIZATION & TAILS	NEUTRALISATION ET RESIDUS MINIERS	0050
10	SULFURIC ACID PLANT	USINE D'ACIDE SULFURIQUE	0090
11	COBALT REFINERY	RAFFINERIE DE COBALT	0080
12	PLS POND - LG	SOLUTION DE LIXIVIATION ENRICHIE - FAIBLE TENEUR	0060
13	PLS POND - HG	SOLUTION DE LIXIVATION ENRICHIE - HAUTE TENEUR	0060
14	RAFFINATE STORAGE POND - LG	BASSIN DE STOCKAGE DU RAFFINAT - FAIBLE TENEUR	0060
15	RAFFINATE STORAGE POND - HG	BASSIN DE STOCKAGE DU RAFFINAT - HAUTE TENEUR	0060
16	SX EMERGENCY POND	BASSIN D'URGENCE SX	0060
17	PROCESS WATER TANK	RESERVOIR D'EAU DE PROCEDE	0110
18	WORKSHOP	ATELIER	0150
19	WAREHOUSE	ENTREPOT	0150
20	MAIN 33kV SUBSTATION	PRINCIPAL POSTE ELECTRIQUE 33kV	0130
21	OFFICE & CONTROL ROOM	BUREAU ET SALLE DE CONTROLE	0140
22	COBALT HYDROXIDE STORE	ENTREPOT D'HYDROXYDE DE COBALT	0140
23	WEIGH BRIDGE	PONT-BASCULE	
24	GATE HOUSE	POSTE DE GARDE	0140
25	REAGENT STORAGE	ENTREPOSAGE DES REACTIFS	0140
26	LABORATORY	LABORATOIRE	0140
27	LIMESTONE & LIME	CALCAIRE ET CHAUX	0103
28	DILUENT & EXTRACTANT	DILUANTS ET AGENTS D'EXTRACTION	0102
29	LEACH CONTAINMENT POND	BASSIN DE CONFINEMENT DU LIXIVIAT	0030
30	CHANGE HOUSE	VESTIARE	0140
31	BREAK ROOM	SALLES DE RECREATION	0140
32	CAR PARK	PARKING	
33	HV SWITCHYARD	CENTRALE ELECTRIQUE	0130
34	HEAVY VEHICLE REFUELING	STATION A ESSENCE POUR VEHICULES LOURDS	
35	STANDBY GENERATORS	GROUPE ELECTROGENE DE SECOURS	0130
36	FUEL STORAGE	ENTREPOSAGE DE CARBURANT	0113
37	HEAVY VEHICLE WORKSHOP	ATELIER DE REPARATION DES VEHICULES LOURDS	0150
38	DRAINAGE POND	BASSIN DE COLLECTE DES EAUX DE RUISSELLEMENT	
39	SULFUR STORAGE	ENTREPOSAGE DU SOUFRE	0140
40	SEWAGE PLANT	USINE DE TRAITEMENT DES EAUX USEES	
41	AIR/COMPRESSOR	AIR/COMPRESSEUR	0111
42	TIRE SERVICE BAY	POSTE DE REPARATION PNEUMATIQUE	
43	SENTRY BOX	GUERITE	0140
44	POTABLE WATER FACILITY	USINE D'EAU POTABLE	0110
45	LIME STORAGE	ENTREPOSAGE DE CHAUX	0140
46	FLOCCULANT PLANT	USINE DE FLOCULANT	0101
47	COBALT ELECTROWINNING	ELECTRO-OBTENTION DU COBALT	0088
48	BOILER HOUSE	BATIMENT DES CHAUDIERES	0112
49	BUS DROP OFF ZONE	ARRET DE BUS	
50	GAS/DIESEL TANKS	RESERVOIRS D'ESSENCE/DIESEL	
51	LEACH DISCHARGE THICKENING	EPAISSISSEMENT DU LIXIVIAT DE DECHARGE	0030
52	RAW WATER POND	BASSIN D'EAU BRUTE	0110
53	FIRE WATER POND	BASSIN D'EAU INCENDIE	0110
54	WATER STANDPIPE	D'EAU TUYAU VERTICAL	
55	LAY DOWN AREA	AIRE DE STOCKAGE	
56	CRUD	RESIDUS SOLIDES D'EXTRACTION	0060
57	MAGNESIA	OXYDE DE MAGNESIUM	0105
58	SODIUM HYDROXIDE	HYDROXYDE DE SODIUM	0106
59	LIME	CHAUX	0104
60	LIGHT VEHICLE REFUELING	STATION A ESSENCE POUR VEHICULES LEGERS	
61	FIRST AID & FIRE BUILDING	POSTE DE POMPIERS ET PREMIERS SECOURS	0140
62	SUBSTATION	POSTE ELECTRIQUE	0130
63	VEHICLE WASH DOWN BAY	STATION DE LAVAGE	



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No.	BY	DATE	REVISION	CHECKED	APPROV.
A	RJC	30.03.07	APPROVED FOR EIA		

	BY	DATE
PROJECT APPR.		
DESIGN APPR.		
DESIGNED		
CHECKED		
DRAWN	R.CARTER	30.03.07

SCALE 1:2500

PLANT GRID NORTH

CLIENT PHELPS DODGE CORPORATION FIGURE C2.6-2

TITLE
TENKE FUNGURUME MINING PROJECT

PLAN D'AMENAGEMENT DE L'USINE DE TRAITEMENT / PROCESSING PLANT LAYOUT

PROJECT No. 52018 | DRG SIZE A1 | DRAWING No. 52018-0000-20-124-159 | REV No. A | ISSUE#:

DRAWING No. | REFERENCE DRAWINGS

Date: 30/03/2007 Time: 12:54:35 PM Plotted By: rcarter Pentable: LZR.TBL Plotdriver: PDF A3 - BW.plt Filename: W:\TENKE\52018\Drawings\General\Design Data\Sketches\52018-0000-20-124-159.dgn

- Occupational hazards.
- Physical hazards.
- Pollution.
- Violent release of energy.
- Maintenance access.

Results from this study included identifying the following major hazard scenarios leading to public or environmental risks:

- In the sulfuric acid plant the loss of electrical power to the scrubber could impact on public safety. Safeguards include interlocks to prevent releases. During detailed design, consequence modeling will be carried out for this hazard scenario in order define the risks to the public and, if appropriate, additional mitigation measures.
- In the leaching unit, loss of electric power to the leach off gas scrubber could release some volume of toxic sulfur dioxide that could impact public safety.
- Discharge of process liquors due to equipment or operator failure which could pollute the surrounding environment. Safeguards include preventative interlocks and minimizing risk through containment.
- In the solvent extraction area there may be some potential conditions for serious fires which could cause off-site public and environmental effects. Safeguards include several engineering and operational measures are described earlier in this section.
- A release, as a result of tank failures or overfilling, could pollute the surrounding environment. Safeguards include building containment areas.
- In the sulfuric acid unit, fires and release of sulfur dioxide or sulfur trioxide could result in public and environmental impacts. Safeguards include detailed hazard and consequence modeling studies.
- Loss of diesel fuel from storage could pollute the environment. Safeguards include containment to industry standards for combustible liquids.
- Any release of harmful or noxious pollutants to the atmosphere could require emergency evacuations in the local communities.

Selected safeguards were identified for each hazard scenario above and a summary of the engineering, administrative and operational risk mitigation measures is presented earlier in this section.

Mining Hazards

Many mining risks are associated with natural hazards. Some hazards result from the man-made facilities constructed on-site and are not the result of a seismic or extreme storm event. Unforeseen geotechnical conditions could occur as an isolated event and potentially cause the following hazard scenarios:

- A landslide along the embankments due to excessive seepage (piping) and/or oversteepening of the embankments. A landslide could cause overtopping or breaching of the embankments.
- A landslide or slumping at the waste rock facilities or excavated slopes due to oversteepening of the slopes which could cause a flow slide.

The likelihood of embankment piping erosion is negligible and the associated consequences are very low (see Section 9.10.5.6 of the feasibility report dam break assessment).

Some amount of explosives will be used for the waste rock. The storage and handling of explosives will be managed by a contractor specializing in these activities. The contractor will be a blasting services company fully licensed in the DRC. Once the type of explosives to be used is determined the type of storage appropriate to that type of explosives will be identified. Details on blasting safety measures is described in Sections A4.3.3 and D3.1.11.

Transportation hazards associated with mining operations on-site are assessed in the following subsection. Engineering and operational risk mitigation measures are summarized earlier in this section.

Transportation Hazards

Major hazards associated with rail and road accidents due to spills or collisions were assessed during a detailed feasibility study on transport and logistics and project development planning. Transportation corridors for rail and road traffic both off-site and on-site are described in the project description, (see Section A4.2). An analysis of the transportation options is described in Section A3.1.15. In addition, projections for project-related traffic are described in Section C2.13. Transportation hazards summarized in this section reference the assessments from these other sections.

Off-site transportation of reagent and fuel supplies for mine operations and export of copper and cobalt product will require adequate logistics planning. The process will use port unloading and storage, rail, dry port transfer of bulk materials from rail to road vehicle and road transport to the mine site, as

described in Section A4.2. The bulk of raw materials and equipment imports and product exports will move through four possible ports: Richards Bay or Durban (South Africa), Dar es Salaam (Tanzania) and Walvis Bay (Namibia). An overview map showing the transportation corridors for both rail and road from these ports to the mine site is presented in Figure C6.2-3.

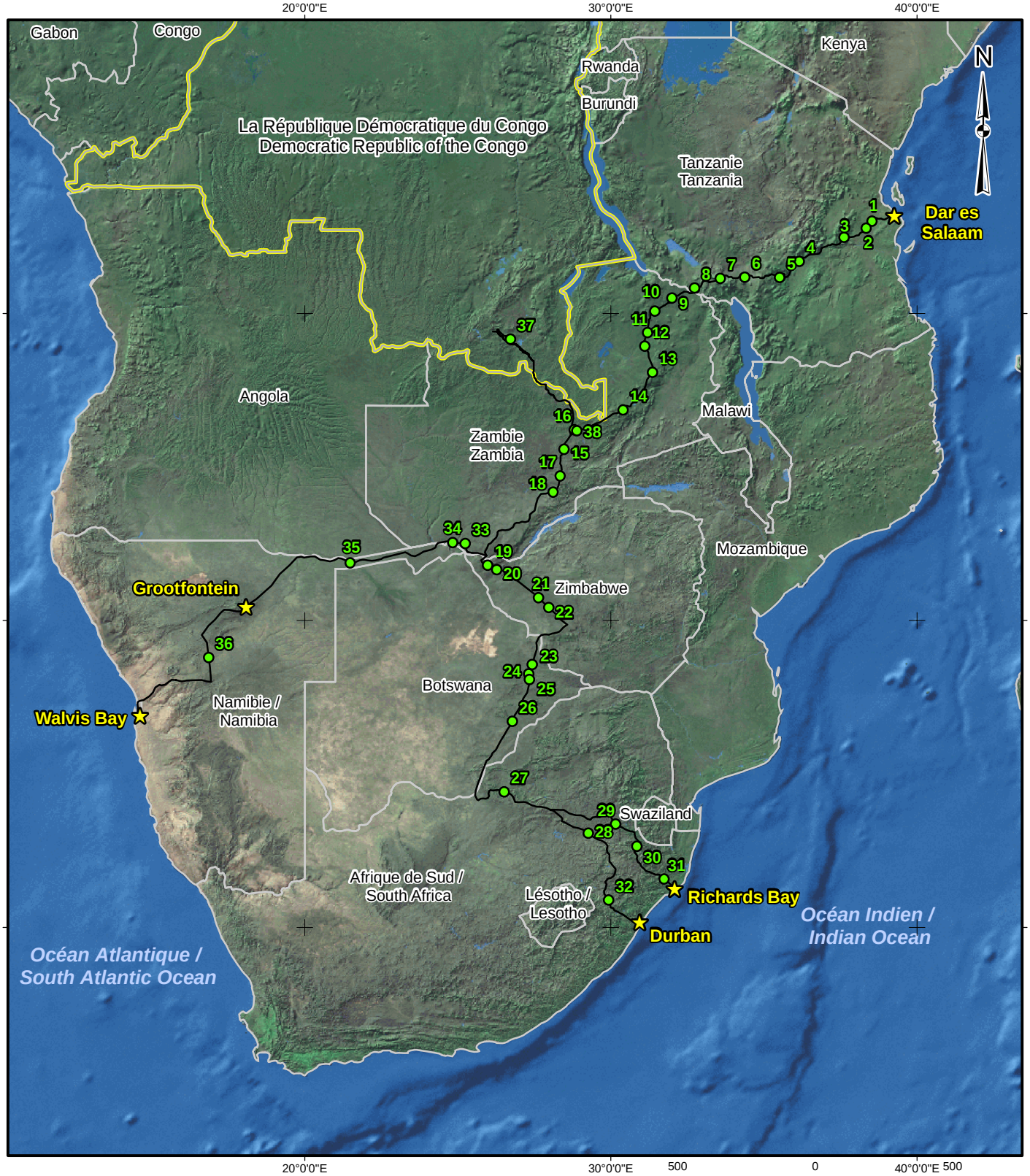
In addition to the rail and road transportation corridors highlighted in Figure C2.6-3, the 38 major river crossings along all corridors are numbered. Major water crossings refer to those permanent rivers of sufficient width to be marked on maps at a 1:4,000,000 scale. The rivers range from very major (Zambezi, with an average discharge at mouth of 7,000 cubic meters per second, although the volume at crossing is much lower) to much smaller rivers. River lengths from headwaters to crossing locations begin at approximately 50 kilometers and range into hundreds of kilometers. The total crossings for each of the four corridors are provided in Table C2.6-3 (from Table A4.2-4).

Table C2.6-3 Major Water Crossings for Off-Site Transportation Routes

Port	Length of Route to Mine Site (km)[(a)]	Total Major Water Crossings	Water Crossing Numbers (from Figure C2.6-3)
Richards Bay	3,210	18	15-27, 29-31, 37-38
Durban	3,400	17	15-27, 28,32, 37-38
Dar es Salaam	2,100	17	1-14, 16, 37-38
Walvis Bay	2,400	9	15-18, 34-38

[(a)] km = kilometers.

These river crossings along with public settlements next to the corridors are assessed as sensitive environmental and public exposures to potential spills. Other sensitive areas include internationally recognized protected areas along these routes (three on the route to Dar Es Salaam; four on the routes to Durban and Walvis Bay; and five on the route to Richards Bay). High-volume bulk materials will be transferred from railcars to road trucks at a suitable facility in Ndola (Zambia), Mufulira or Lubumbashi both in the Democratic Republic of the Congo (DRC). A larger-scale map of this area to the mine site is presented in Figure C2.6-4. On the final part of the truck transport route, truck traffic may bypass the national road (until maintenance is improved to allow heavy traffic) from Likasi to Fungurume (Figure C2.6-5). The principal on-site roads are also shown on this map including the bypass road to limit public exposure around Fungurume. Public exposure from vehicle, bicycle and foot traffic along the truck roads will affect the risk of accidental collisions with the mine trucks, both on- and off-site. Impacts from incremental traffic along the roads near the plant site are assessed in Section C2.13.



LÉGENDE / LEGEND

- VILLE PRINCIPALE / MAJOR CITY
- TENKE
- EMPLACEMENTS DES POINTS DE FRANCHISSEMENTS DES COURS D'EAU / WATER CROSSING LOCATIONS
- CHEMIN DE TRANSPORT / TRANSPORTATION ROUTE
- PAYS / COUNTRY
- LA RÉPUBLIQUE DÉMOCRATIQUE DU CONGO / DEMOCRATIC REPUBLIC OF THE CONGO

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Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE **ROUTES DE TRANSPORT HORS SITE DU CARBURANT ET DES PRODUITS / OFFSITE TRANSPORTATION ROUTES FOR FUEL AND PRODUCTS**

Golder Associates
Calgary, Alberta

N° projet / project no. 05-1334-035.9300			Échelle telle qu'indiquée Scale as Shown	REV. 0
DESSIN / DESIGN	MR	16 Mar. 2005		
SIG / GIS	TN	04 Jan. 2007		
VÉRIFIÉ / CHECK	MR	21 Jul. 2006		
APPROUVÉ REVIEW	MR	21 Jul. 2006		

FIGURE: C2.6-3

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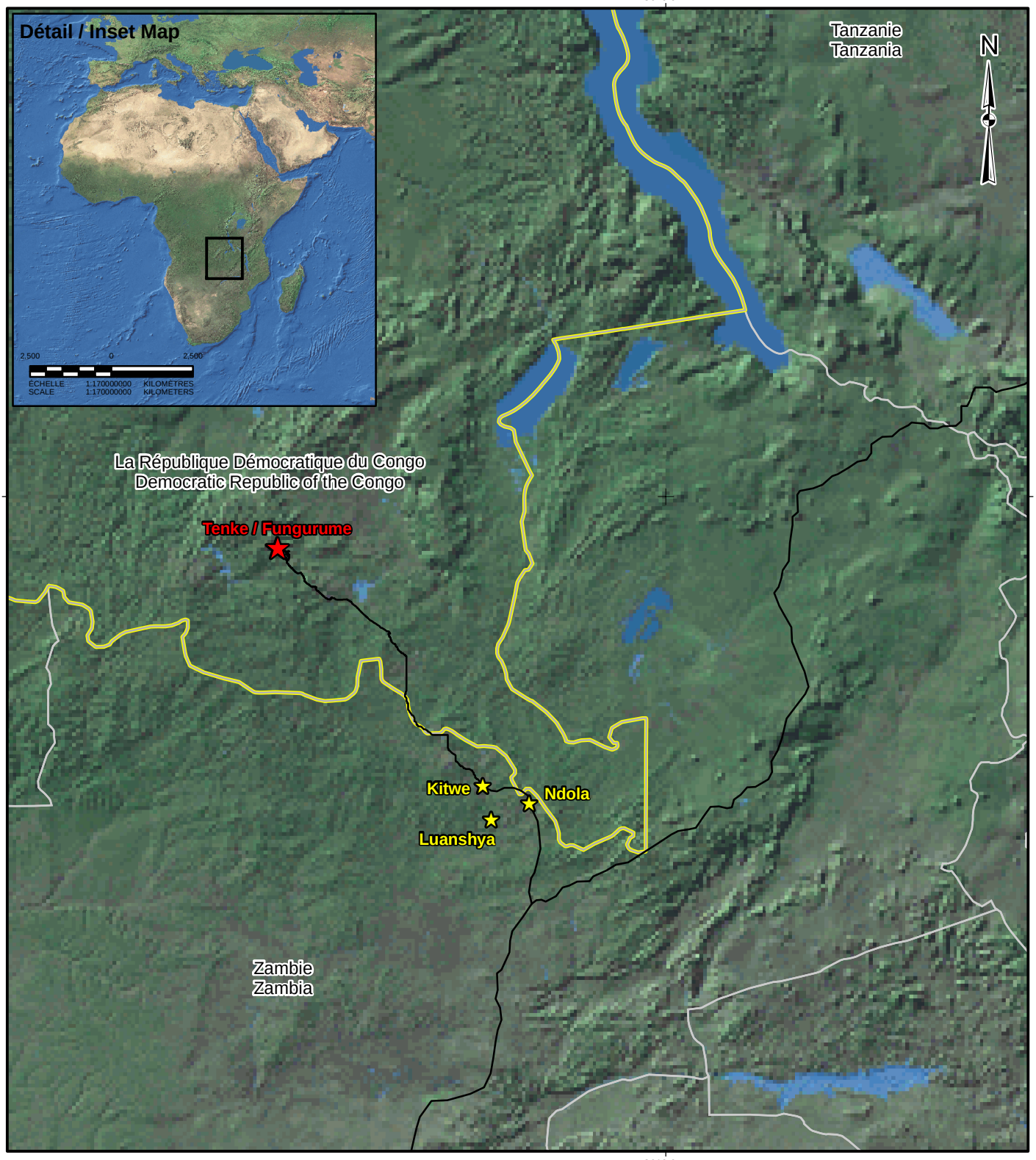

LÉGENDE / LEGEND

- VILLE PRINCIPALE / MAJOR CITY
- TENKE / FUNGURUME
- CHEMIN DE TRANSPORT / TRANSPORTATION ROUTE
- PAYS / COUNTRY
- LA RÉPUBLIQUE DÉMOCRATIQUE DU CONGO / DEMOCRATIC REPUBLIC OF THE CONGO

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Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

ROUTE DE CAMIONNAGE NDOLA -- FUNGURUME /
TRUCK TRANSFER ROUTE FROM NDOLA TO FUNGURUME

Golder Associates
Calgary, Alberta

N° projet / project no. 05-1334-035.9300			Échelle telle qu'indiquée Scale as Shown	REV. 0
DESSIN / DESIGN	BG	04 Jun. 2006		
SIG / GIS	TN	04 Jan. 2007		
VÉRIFIÉ / CHECK	MR	01 Aug. 2006		
APPROUVÉ REVIEW	MR	01 Aug. 2006		

FIGURE: C2.6-4

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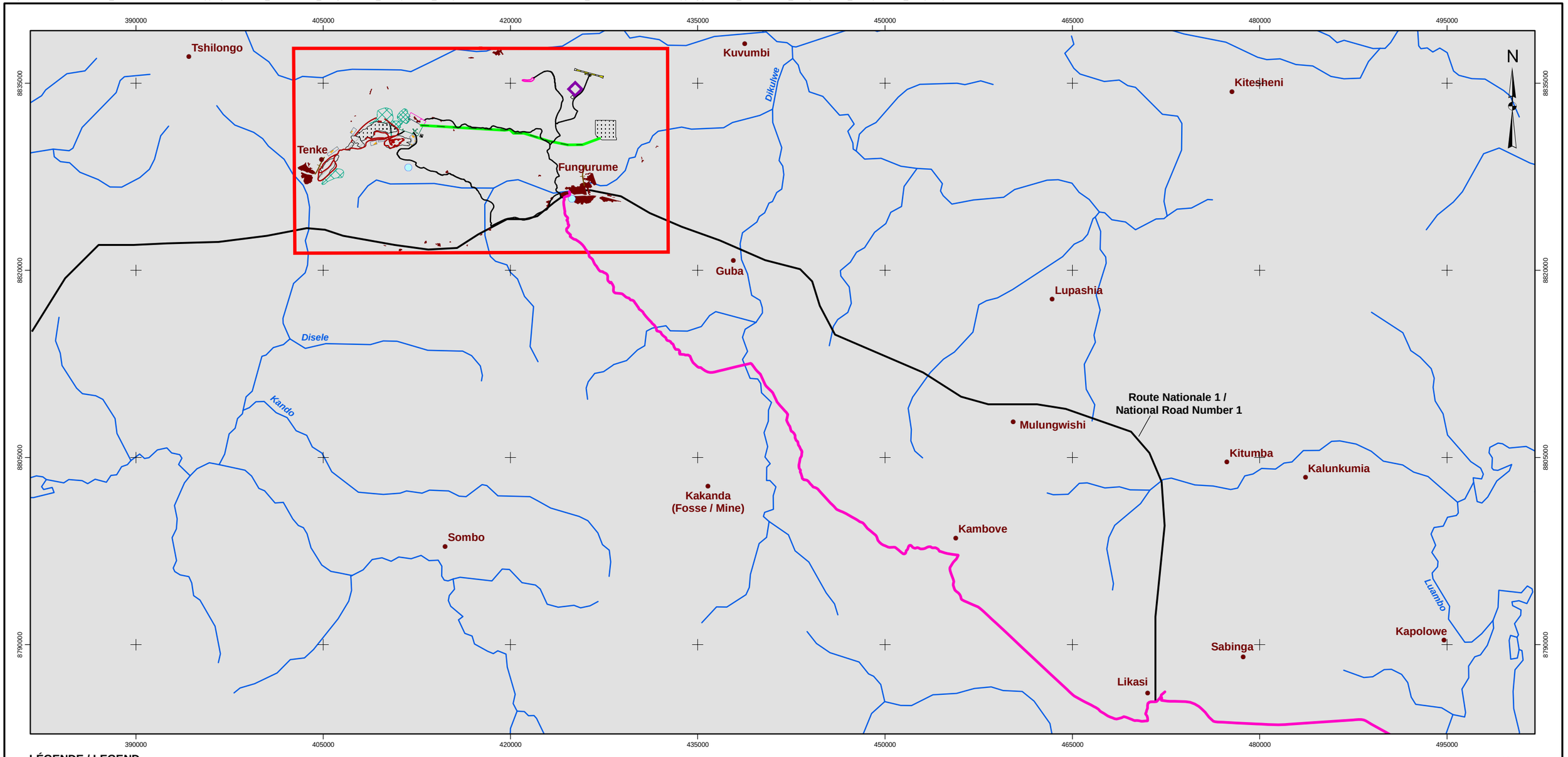

LÉGENDE / LEGEND

- VILLAGE
- RIVIÈRE / RIVER
- ROUTE NATIONALE 1 / NATIONAL ROAD NUMBER 1
- ROUTE DE TRANSPORT / TRANSPORTATION ROUTE
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- ZONE D'ÉTUDE RÉGIONALE / REGIONAL STUDY AREA

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

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ÉCHELLE / SCALE 1:300000 1:300000 KILOMÈTRES / KILOMETERS

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

ROUTE DE TRANSPORT LIKASI -- FUNGURUME /
TRUCK TRANSPORT ROUTE FROM LIKASI TO FUNGURUME

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035		ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	GJ	22 Jun. 2006	
GIS / SIG	TN	04 Jan. 2007	
VÉRIFIÉ / CHECK	MR	20 Oct. 2006	
APPROUVÉ / REVIEW	MR	20 Oct. 2006	

FIGURE: C2.6-5

Construction supplies and equipment, reagents, fuel, products and equipment for operations will be transported along the off-site corridors. The primary materials to be transported along the on-site roads will be ore and waste rock as described in the project description (see Section A4.2).

The estimated supplies required for the "first fill" to be transported to the site in advance of operations are listed in Table C2.6-4 (from Table A4.2-2). A total of approximately 765 full truck trips (not including back haul) are required to supply these quantities. In addition to this, around 670 full truck trips are required to transport equipment, steel and cement for the construction of the process plant. Three hundred vehicles for the mining fleet, cranes and other mobile equipment will also be transported to site.

There will also be a requirement for 70,000 tonnes of aggregate and sand for construction, which will be sourced close to the process plant site.

During operations, the estimated daily truck and rail supply import requirements are shown in Table C2.6-5. The daily truck and rail product export requirements are shown in Table C2.6-6 (from Tables A4.2-2 and 3).

As shown in these tables, an estimated total average daily volume of 11 bulk trucks, two magnesia container trucks and two fuel tanker trucks will travel the off-site roads from the origins shown to supply the mine with needed materials during operations. It is estimated that 10 trucks per day of limestone will only travel on-site between the quarry and the plant. Also, an average of 10 trucks per day will export copper and cobalt product from the mine site. These 10 trucks may be used in a back-haul mode with trucks supplying the mine. Railcar volume between the dry port and the import and export ports average five sulfur rail cars per day inbound and eight copper rail cars per day outbound.

Transportation hazards from the accidental spills are dependent on exposure to the environment and the public. The consequences will depend on the acute toxicity of the material, the volume spilled and its relative fate and persistence. Spill risks are dependent on the transportation exposure in terms of trip kilometers, the spill accident frequency, the public and environmental exposure and the spill consequences. Collision risks are dependent on the transportation exposure in terms of trip kilometers, the injury accident frequency and the public exposure. Risk mitigation measures will address all of these factors in the transportation program.

Table C2.6-4 First Fill Quantities of Reagents to be Imported to the Site

Reagent	First Fill and Initial Stock (tonnes)	Average Number of Trucks Required
grinding media	215	6
flocculant	70	2
coagulant	137	7
extractant	634	19
diluent – cubic meters	1,701	57
quicklime	5,158	152
hydrated lime	4	<1
tri sodium phosphate	1	<1
hydrazine	1	<1
sodium hypochlorite	243	7
magnesium oxide	1,500	71
sulfur	9,403	277
sulfuric acid[(a)]	1,000	33
glucosol CH_4	9	<1
bentonite clay	21	1
antiscalant	16	<1
polyolefin prills (19 mm)	99	3
sodium hydroxide	801	24
garnet	161	5
anthracite	157	5
boric acid	24	1
soduim lauryl sulphate	0	<1
strontium carbonate	1	<1
strapping	10	<1
sodium hydrosulfide	10	<1
zinc ion exchange resin	47	2
nickel ion exchange resin	36	1
carbon	13	<1
cobalt packaging	68	2
diesel	2,742	91
Total	**24,282**	**765**

mm = millimeters.

[(a)] Imported only for first fills, for the commissioning of the acid plant. After this, sulphuric acid will be produced on-site.

Table C2.6-5 Estimated Annual Material Transport Requirements during Operations

Material	Annual Average				Daily Average[a]						Origin	Mode of Transport	Backload Possible
	t	m^3	Containers	Tankers	t	m^3	34 t Trucks	40 t Rail Cars	Containers	Tankers			
sulfur	72,947	n/a	n/a	n/a	200	n/a	6	5	n/a	n/a	Richards Bay /Dar es Salaam	road / rail	yes
quicklime	39,528	n/a	n/a	n/a	108	n/a	3	n/a	n/a	n/a	Ndola	road only	yes
limestone	108,540	n/a	n/a	n/a	297	n/a	10[b]	n/a	n/a	n/a	Quarry[c]	road only	no
magnesia containers	11,745	n/a	559	n/a	n/a	n/a	n/a	n/a	2	n/a	Durban	road only	no
coagulant / diluent tankers	1,106	1,229	n/a	41	n/a	3	n/a	n/a	n/a	<1	Durban	road only	no
fuel tankers	13,161	16,451	n/a	548	n/a	45	n/a	n/a	n/a	2	Ndola / Dar es Salaam	road only	no
consumables	5,000	n/a	n/a	n/a	14	n/a	<1	n/a	n/a	n/a	various	road only	yes
other reagents	6,525	n/a	n/a	n/a	18	n/a	1	n/a	n/a	n/a	Durban / Walvis Bay / Dar	road only	yes
copper cathode	115,000	n/a	n/a	n/a	315	n/a	9	8	n/a	n/a	Tenke	road / rail	yes
cobalt rounds	8,000	n/a	n/a	n/a	22	n/a	1	n/a	n/a	n/a	Tenke	road only	yes
cobalt hydroxide	4,545	n/a	n/a	n/a	12	n/a	<1	n/a	n/a	n/a	Tenke	road only	yes

[a] Daily figures represent the number of units that would be required if only that method of transport were used.

[b] Limestone transport is based on 30-tonne dumptrucks

[c] Sourced from the Mofia pit on the concession.

Note: Included are: gas cylinders, lubricants, spare parts and tires.

Table C2.6-6 Product to be Shipped from Site and Alternative Transport Routes

Port	Length of Route (km)	No. of Major Water Crossings	Mode of Transportation	Product (tonnes per year)	Daily Average		
					Tonnes	Trucks	40 t Rail Cars
Dar es Salaam	2,100	17	road/rail	copper 115,000	315	9 (mine to Zambia)	8 (Zambia to port)
Durban	3,400	17	road/rail				
Dar es Salaam	2,100	17	road	cobalt metal 8,000	22	1	n/a
Walvis Bay	2,400	9	road				
Durban	3,400	17	road				
Dar es Salaam	2,100	17	road	cobalt hydroxide 4,545	12	<1	n/a
Walvis Bay	2,400	9	road				
Durban	3,400	17	road				

n/a = Not applicable.

The following major hazard scenarios leading to public or environmental risks were identified from the preliminary assessments described above. All issues identified from stakeholder consultations were also included in these hazard scenarios.

- Accidental spills of reagents at port facilities that could cause environmental releases.
- Sulfur storage and handling hazards include potential fires and explosion (from dust and hydrogen sulfide gas) and evolution of hydrogen sulfide gas.
- Accidental spills of fuel or diluent, high-volume reagents (sulfur, magnesium oxide, quicklime) and low-volume but high-toxicity reagents in transport or storage could cause releases into the environment.
- Accidental collisions resulting in public casualties.
- Dust on-site from transportation activities impacting the nearby public.
- Public exposure to dangerous open culverts for on-site roads could lead to public injuries.

Selected safeguards were identified for each hazard scenario above. Mitigation is listed below. A summary of the engineering, administrative and operational risk mitigation measures is presented in an earlier section.

- Existing modern handling and storage facilities and risk management programs will be used in all ports.

- Risk mitigation measures for transport include design of containers, use of formed sulfur and operating procedures, as discussed in the project description (see Section A4.2.2.1). Port and transfer facilities will carry out detailed risk assessments before operations.
- A risk management program will be used to implement accident prevention and emergency response measures (Section D7) especially near sensitive environmental exposures (Figure C2.6-3 and in any internationally-recognized protected areas) and public exposures. This risk-based approach will be incorporated into the mine's hazardous materials management program. Risk mitigation measures include accident prevention (these measures are summarized in an earlier section) and consequence minimization, such as container design, to minimize spill severity following an accident.
- Public exposures to rail crossings and to truck road traffic will be minimized where possible (i.e., procedures at rail crossings, bypass road from Likasi to Fungurume and around Fungurume as shown in [Figure C2.6-5], design of Class 3 roads on-site to separate pedestrian and bicycle traffic from mine vehicle traffic. The class 3 roads will include a physical or visual barrier between the two traffic paths [Section A4.2.1.2]). Equipment, driver and administrative prevention measures are described in an earlier section.
- Dust impacts and associated mitigation measures are addressed in Section C2.8.
- Mitigation measures include improved designs and construction scheduling to minimize exposure.

Impact Analysis

During construction and operation, impacts from major hazards will be managed through minimizing risk. Risk analyses will be conducted within an ongoing management program to control risks from all major hazards. Residual natural risks and those from the processing plant, mine and transportation activities are expected to be in the low to moderate risk rating as defined in the project risk matrix. Such ongoing analyses minimize risk to the public and to environmental resources. The residual risks are within international standards for mining operations.

During the closure phase, natural risks will be managed through implementing engineering risk mitigation measures as part of the closure plan. Residual natural risks are expected to be in the low risk rating as defined in the project risk matrix.

Prediction Confidence

Risk estimates are made taking into consideration variation in data and prediction confidence. However, risk ratings are also dependent on the success of the proposed mitigation measures as described in this major hazard assessment. Overall, the prediction confidence for this ESIA assessment is considered moderate. As the project progresses to detailed engineering, risk estimates will be refined in an ongoing risk management program. It is expected that mitigation measures will also be implemented as appropriate depending on the results of future risk assessments. As a result, the estimated residual risks from major hazards are expected to remain in the low or moderate categories.

Monitoring

Monitoring programs were summarized in the risk mitigation measures. Monitoring programs include instrumentation and inspections for geotechnical assessments and for processing plant operations.

C2.6.3.5 Sustainability Assessment

Sustainability assessments were completed for the physical, biological and social impacts from the TFM project in order to address how the project can influence these impacts to have long-term positive effects. Major hazards are assessed according to the risks of negative effects occurring; therefore a sustainability assessment is not applicable for major hazards. However, some mitigation measures that minimize the risk of major hazards occurring may also affect other physical, biological and social impacts. These are addressed in the relative sustainability assessments.

An example is presented in the sustainability Section C2.1.3.5 for topography and geomorphology. The post-closure landscape of the TFM project will be developed with specific principles. Sites will either be returned to a safe and stable condition or appropriate safeguards will be put in place to minimize public exposures, which in some areas will represent an enhancement over the baseline condition. These measures will minimize the risk of slumping (a potential major hazard) and are assessed in the residual impact classification for sustainability in Section C2.1.3.5.

C2.6.4 Cumulative Effects Assessment

Assessment Methods

The cumulative effects assessment considers expanding the project to a production rate of 400,000 tonnes per year of copper. Such an expansion would require construction of a second processing plant north of Fungurume and mining of the Fungurume deposits.

Although detailed plans for an expansion are not yet available, the concept was reviewed in a relative comparison with the base case assessment for major hazards. The following assumptions were made:

- Mining of ore at Kwatebala, Goma, Fwaulu and Fungurume.
- Expansion of the proposed Kwatebala processing plant to a production of 200,000 tonnes per year of copper.
- Construction of a second processing plant north of Fungurume with a production of 200,000 tonnes per year of copper.
- Use of an above-ground tailings storage facility north of Fungurume, in addition to the existing western tailings facility.
- Deposition of waste rock near Goma, Fwaulu, Kwatebala and Fungurume hills.

Assessment methods were based on those used for the base case assessment. Professional experience was used to extrapolate the assessment (see Section C2.6.3) for a general understanding of the above assumptions.

Mitigation

Most of the mitigation measures proposed for key question TG-1 are relevant for an expanded 400,000 tonnes of copper per year project and would be applied to the new facilities and operations. However, specific assessments would be required to refine which mitigation measures are appropriate, and whether specific assessments to refine the use of mitigation measures will help determine if further mitigation is appropriate, especially for the increased exposures from:

- New processing plant.
- New tailings storage facility.
- New mine operations.
- New waste rock facilities.

- Increased volume of transportation for reagents, fuel and products.

Mitigation measures would develop from the standard hazard identification studies completed as the expansion project moves from concept to development. Some measures applied for the base case may not be practical for the expansion case. For example, buttressing the base case tailings storage facility embankment with the waste rock facility may not work for the expansion tailings storage facility.

Results

The principal effects of the expansion project on major hazards would be an increase in the exposure to hazard scenarios associated with the increase in number of facilities and volume of transportation required. However, the types of hazard scenarios are expected to be similar. Similar mitigation measures would also generally apply although these would be verified through hazard identification studies.

Impact Analysis

During construction and operations, impacts from major hazards will be managed through risk minimization in a similar process for the expansion project as for the base case project. Risk analyses will be completed within an ongoing management program to control risks from all major hazards. It would still be expected to keep residual natural risks and risks from the processing plants, mines and transportation activities in the low to moderate risk rating as defined in the project risk matrix.

During the closure phase, natural risks will be managed through engineering risk mitigation as part of the closure plan. Residual natural risks are expected to be in the low risk rating as defined in the project risk matrix.

Prediction Confidence

Overall, the prediction confidence for the base case assessment of major hazards is considered moderate. Although hazard identification studies have not been completed for the expansion project, it is expected that risk mitigation measures will be implemented as appropriate depending on the results of future risk. As a result, the prediction confidence is lower for the expansion project, but would be similar to the base case once future studies are completed.

C2.6.5 Conclusions

Following implementation of mitigation measures, the residual risks of major hazards for the public and the environment as a result of the TFM project are estimated to be low to moderate and within international standards.

For the cumulative effects case with a project expansion from 115,000 to 400,000 tonnes of copper per year, it would still be expected to keep residual risks from major hazards in the low to moderate risk rating, as defined in the project risk matrix.

C2.7 CLIMATE

No assessment is required for this discipline. This section is included to allow for consistency in section numbering between Volumes B and C.

Greenhouse gases, which affect climate, are assessed in Section C2.8.

C2.8 AIR QUALITY IMPACT ASSESSMENT

C2.8.1 Introduction

This section presents the environmental assessment for the effects of the Tenke Fungurume Mining (TFM) project on air quality as per the project's terms of reference (Appendix E8). The information presented includes details on:

- Project activities that may affect air quality.
- Potential issues regarding changes to air quality.
- Methods used for the analysis of air quality effects.
- Impact assessment approach and results for key air quality issues.
- Mitigations incorporated in the project design for these impacts.
- Sustainability assessment approach and results for air quality issues.
- Identified measures relating to air quality to promote long-term economic and social sustainability in the project area.

The primary airborne compounds associated with the proposed project include sulfur dioxide (SO_2), nitrogen dioxide (NO_2), inhalable particulate matter (PM_{10}), total suspended particulates (TSP), volatile organic compounds (VOCs) and carbon dioxide (CO_2). In the immediate area of the processing plant, minor amounts of sulfuric acid mist will also be released. These pollutants would originate from the proposed processing plant, materials handling activities, crushing and milling, drilling and vehicle entrainment. Other emissions would be associated with blasting activities and would include carbon monoxide (CO).

The predicted ground-level concentrations of the above compounds have been assessed with respect to applicable local and international regulatory requirements (Section A2.7). Details on the methodology and approach to the assessment are provided in Appendix C2.8-I.

This section is organized as follows:

- Section C2.8.2 describes the study areas.
- Section C2.8.3 discusses the impact assessment and sustainability assessment approach and results.
- Section C2.8.4 provides the cumulative effects assessment.
- Section C2.8.5 discusses the conclusions of the assessment.

The baseline information regarding local climatic conditions in the region as well as ambient air quality is given in Sections B2.7 and B2.8 respectively.

A glossary of terms and acronyms used is provided at the back of this volume.

C2.8.2 Study Areas

A Local Study Area (LSA) of 20 kilometers by 20 kilometers was selected to allow for the assessment of project-specific impacts on local air quality (Figure C1.1-1).

The LSA was used to identify specific sensitive receptors for the assessment. Any named villages in the region that were identified within two kilometers of the proposed mine, facilities, limestone quarry and within distances of 500 meters from roadways were considered sensitive receptors. The villages identified as sensitive receptors for the air quality assessment are (Figure C1.1-1):

- Tenke.
- Fungurume.
- Kafwaya.
- Kwatebala Gare.
- Mulumbu Kiasa.
- Mwela Mpande Gare.
- Bloc Mitumba.
- Salabwe.
- Mwanga Bijimba.
- Mwanga Muteba (Shungu).

These villages were determined to be the primary residential areas within the LSA, based on the results of the socio-economic surveys (Section B4.1). The villages of Mulumbu, Amoni and Kiboko are not included in the list of sensitive receptors since they will be relocated (Section D4.4).

A Regional Study Area (RSA) was also defined for analysis of impacts of the expanded project. It is a larger area (i.e., 31.5 kilometers [east-west] by 20 kilometers [north-south]) and includes a potential plant site north of Fungurume (Section C1.1).

C2.8.3 Impact Assessment

C2.8.3.1 Issue Scoping

As described above, air emissions may occur during site preparation/construction, operation and closure. Each of these phases is discussed below in the context of potential air quality issues.

Site Preparation and Construction

Early site preparation and construction will comprise different activities including land clearing, topsoil removal, material loading and hauling, stockpiling, grading, bulldozing, compaction, etc. Each of these activities has the potential for fugitive dust generation. It is therefore likely that dust emission rates will vary substantially from day to day depending on the level of activity, the specific operations and the meteorological conditions. The type of particulate matter associated with fugitive dust, however, is of a large enough diameter that much of it will fall out within a relatively short distance from the source (i.e., within the boundaries of the project site). Heavy-duty vehicles and stationary construction equipment would generate diesel exhausts.

Operation

During the operation phase of the proposed project (with a copper production of 115,000 tonnes per year), atmospheric emissions would be generated from the processing plant, mining operations as well as related vehicle activities. The sources of emissions from the processing plant would consist of the sulfuric acid plant stack, leach stack, the iron removal vents and the copper precipitation vents. Non-stack fugitive emissions from the plant include volatile organic compound (VOC) emissions from the solution extraction facility and sulfuric acid mist emissions from the electrowinning tankhouse. The sources of emissions from the mining activities will consist of materials handling, crushing, wind erosion from storage piles, vehicle fuel combustion, vehicle entrainment, drilling and blasting (if this option is considered). Atmospheric emissions from these sources would include nitrogen dioxide (NO_2), carbon monoxide (CO), inhalable particulate matter with a diameter of less than 10 micrograms (PM_{10}), total suspended particulates (TSP) and greenhouse gases such as carbon dioxide (CO_2).

Closure

Closure operations would normally consist of demolition of the plant and rehabilitation of the tailings and waste rock storage piles. Demolition operations

result in a potential for dust generation but emissions vary substantially from day to day depending on the level of activity. As the particulate matter consists of large matter the fallout is normally close to the activity. Thus the activity would not result in high concentrations that would have long-term health or ecological impacts beyond the proposed plant boundaries.

Issue Summary

Air quality assessment issues related to construction include:

- Particulate emissions (dust) from the construction and site clearing operations.
- Tailpipe emissions from heavy-duty vehicles and construction equipment.

Air assessment issues related to operation include:

- Particulate emissions will arise from the mining and processing operations (i.e., wind blown dust from storage piles and tailings, material handling, drilling and blasting activities), as well as from traffic associated with the operations.
- Emissions from the operation of the proposed project (i.e., vent and stack sources) will potentially result in increased ambient air concentrations at sensitive receptors (i.e., human settlements and agricultural land).
- Tailpipe emissions from heavy-duty vehicles.

Air assessment issues related to reclamation and closure include:

- Particulate emissions from the demolition of the processing plant.
- Tailpipe emissions from heavy-duty vehicles and demolition equipment.
- If the exposed surfaces (i.e., tailings storage facility, waste rock facilities and mining areas) are not rehabilitated, particulate emissions due to wind erosion may increase ambient air concentrations.

Air quality issues of stakeholders stem from historical experiences with other mines. During consultation, stakeholders raised issues regarding air pollution including:

- Potential effects on human health, such as respiratory and other diseases.

- Effects on natural vegetation.
- Effects to agriculture, such as fruit trees not bearing fruit, crops failing or not growing well, or reduction in the fertility of agricultural soils.
- Greenhouse gases.
- Dust emissions may escape from the tailings in the tailings storage facility when the water evaporates.

The majority of the air quality impacts associated with the project are expected to occur during the construction and operation phases of the project. With the exception of dust along the access road, potential air quality impacts during project operations are expected to be greater than those during construction.

C2.8.3.2 Key Questions and Indicators

The potential air quality issues have been summarized in a series of key questions that are provided in Table C2.8-1. As part of the impact assessment a sustainability key question was included to allow for the consideration of potential air quality improvements in the region and adjacent to the project.

Table C2.8-1 Key Questions for Air Quality

Impact Assessment
AQ-1 What effect will construction emissions have on air quality in the receiving airshed?
AQ-2 What effect will emissions from operation of the proposed project have on air quality in the receiving airshed?
AQ-3 What effect will closure emissions have on air quality in the receiving airshed?
Sustainability Assessment
AQ-4 How can the project have a long-term positive effect on the receiving airshed?

The Global Reporting Initiative (GRI 2005a) and International Federation of Consulting Engineers (FIDIC 2006) were used to identify key air quality indicators. Table C2.8-2 provides a description of these indicators and how they have been adapted for use in the ESIA.

Table C2.8-2 Indicators for Air Quality

GRI Indicators [a]		FIDIC Indicators[b]		ESIA Indicators
EN10	oxides of nitrogen (NO_X), sulfur dioxide (SO_2), and other significant air emissions by type including particulate matter (i.e., inhalable particulate matter (PM_{10}) and total suspended particulates (TSP)	EN03	quantities of key air pollutants emitted in all phases of project	changes in air quality as a result of the proposed project
EN8	greenhouse gas (GHG) emissions	EN01	quantities of GHGs emitted in all phases of project	changes in GHG emissions

[a] Global Reporting Initiative (GRI 2005).

[b] International Federation of Consulting Engineers (FIDIC 2006).

C2.8.3.3 Assessment Criteria

The air quality assessment for the project has focused on the potential impacts during project operation. While on-site emissions will occur during construction, most of these are expected to be lower than during operations. Therefore, only a qualitative assessment was conducted for construction (key question AQ-1). The quantitative impact assessment completed for operations (key question AQ-2) represents a conservative evaluation of the possible impacts associated with on-site emissions during normal facility operations. The potential effects of closure on air quality were assessed qualitatively due to the intermittent nature and type of emissions at closure.

The objective of the air quality assessment is to predict changes in ambient air quality and ascertain whether the applicable standards and guidelines are achieved. Air quality effects on workers within the active project area (i.e., within the facility fenceline) are governed by occupational health and safety guidelines and thus were not considered in the assessment.

The air quality assessment has considered the range of potential emissions that could occur from the operations of the project. The assessment has included a full evaluation of TSP and respirable particulates (PM_{10}), emissions associated with the mine vehicle exhausts, mining operations, on-site and off-site traffic, the refining operations and those due to wind erosion. While the air quality effects due to particulate emission sources are expected to the be the most notable impact associated with the project, the air quality assessment has also considered the combustion emissions of sulphur dioxide (SO_2) oxides of nitrogen (NO_X) and carbon monoxide (CO), as well as release of VOCs and odor. Combustion emissions are due primarily to the emissions from the on-site mine fleet while sulfite (SO_3) emissions are primarily associated with the acid plant and hydrogen sulphates (H_2SO_4) due to acid plant and electrowinning processes. Windblown-dust results from the exposed areas.

The impact of air emissions released into the atmosphere can be broad, having direct and indirect effects on humans, animals, vegetation, soil and water. For these reasons, environmental regulatory agencies have established ambient air concentration limits for a range of air quality compounds. A summary of the air quality guidelines standards used in this assessment is provided in Section A2.7.1.

Air quality impacts associated with the project are evaluated according to the assessment methodology that has been described in Section A5. This approach involves quantifying the emissions, assessing the residual effects to air quality, and estimating the environmental consequences. Each impact is first described in terms of the direction, magnitude, geographic extent, duration, reversibility and frequency. The impact assessment criteria for air quality are provided in Table C2.8-3.

Table C2.8-3 Impact Criteria for Air Quality

Direction[(a)]	Magnitude[(b)]	Geographic Extent[(c)]	Duration[(d)]	Reversibility[(e)]	Frequency[(f)]
negative: an increase in emissions and/or ambient concentrations	**low**: concentrations do not exceed the guidelines beyond the project site **high**: concentrations exceed the applicable guidelines beyond the project site	**local**: effect restricted to the LSA **regional**: effect extends beyond the LSA into the RSA	**short-term:** less than 3 years **medium-term**: 3-20 years **long-term**: more than 20 years	**reversible**: effects on air quality will cease when operations cease	**low:** occurs once or rarely **medium**: occurs intermittently **high**: occurs continuously

(a) Direction: positive or negative effect for measurement endpoints.

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

(c) Geographic Extent: are affected by the endpoint.

(d) Duration: length of time over which the environmental effect occurs. Considers a 2-year construction period and a 20-year operation period.

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

(f) Frequency: how often the environmental effect occurs.

C2.8.3.4 Key Question AQ-1

Key question AQ-1 is: What effect will construction emissions have on air quality in the receiving airshed?

Linkage Evaluation

Figure C2.8-1 provides the linkage diagram for key question AQ-1. During the construction phase, tailpipe emissions are expected to be lower than those during the operation phase. However there is potential for relatively high dust generation during construction. Despite this, there are a number of mitigation options available to reduce fugitive dust levels. This linkage is valid.

Heavy-duty vehicles and stationary construction equipment would generate diesel exhausts. These pollutants disperse into the surrounding air while the vehicle is in operation. This linkage is valid.

Both the effects of dust and emissions from construction lead to key question AQ-1 (Figure C2.8-1). Other disciplines potentially affected include visual aesthetics, flora, fish and fish habitat and people.

Assessment Methods

Due to the intermittent nature of construction and clearing activity and the relatively lower combustion emissions a qualitative assessment was completed.

Mitigation

Dust control measures which may be implemented during the construction phase are outlined in Table C2.8-4. Control techniques for fugitive dust sources generally involve watering, chemical stabilization, and the reduction of surface wind speed through the use of physical covers such as windbreaks and enclosures. Additional mitigation is described in the air quality action plan (Section D3.1.3).

Results

Carbon Dioxide (CO_2)

Total diesel usage for the construction of the processing plant and mining (peak for the period 2007 to 2008) was given to be 8,943 and 5,337 kiloliters per year, respectively. The estimated carbon dioxide emissions from the construction phase would be about 0.06 million metric tons per year. This should be seen in the perspective of the annual DRC, Africa and global emission rate of GHGs, which is approximately two million metric tons, 861 million metric tons and 26,778 million metric tons, respectively expressed as carbon dioxide (CO_2) equivalent (CO_2E) (Marland et al. 2006). The combination of the processing plant construction and initial mining operations emissions therefore contribute approximately 2.12 percent of the DRC GHG emissions and 0.004 percent of Africa's total GHG emissions. This is equivalent to 0.0001 percent of global GHG emissions.

Figure C2.8-1 Linkage Diagram for Air Quality Key Question AQ-1

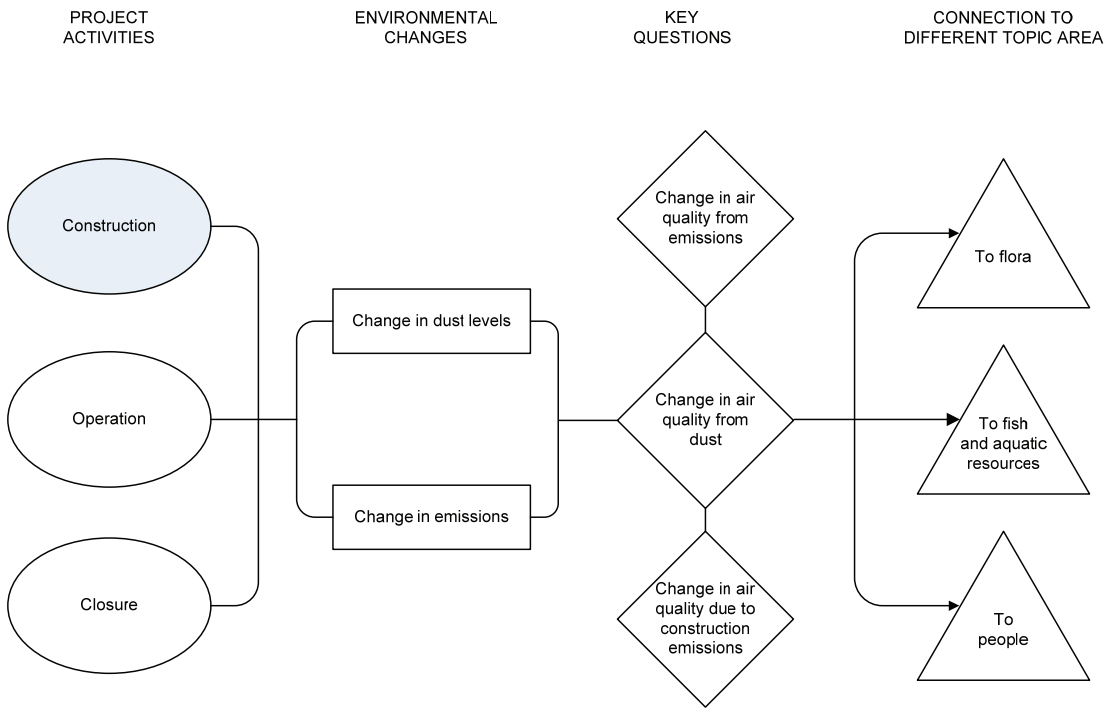


Table C2.8-4 Potential Dust Control Measures for the Project

Construction Activity	Control Measures
truck transport and road dust entrainment	Where possible and for high-risk sites, pave or treat the surfaces of major TFM traffic routes. Paving is highly effective but is expensive and unsuitable for surfaces used by very heavy vehicles or subject to spillage of material in transport. In addition, dust control measures will usually still be required on the paved surfaces. The use of gravel can be moderately effective, but repeated additions will usually be required.
	Reduce vehicle speeds on paved roads or treated surface roads at the site and on unpaved surfaces near villages. Speed controls on vehicles have an approximately linear relationship to dust emissions.
	Wet suppression of unpaved or untreated roads should be applied during dry windy periods, using a water truck.
	Chemical suppression can also be used in conjunction with wet suppression. This involves the use of chemical additives in the water, which help to form a crust on the road surface and bind the dust particles together. Chemical stabilization reduces watering requirements, but any savings can be offset by the cost of the additives. Repeat treatments are usually required at intervals of one to four weeks. The method is best suited to permanent site roads and usually not cost-effective on temporary roads, which are common in mines and construction sites.
	Inspect haul roads for integrity and repair if required.
	Provide hard-standing areas for vehicles and regularly inspect and clean these areas.
	Reduce mud/dirt carry-out onto paved roads through appropriate vehicle routing and/or washing.
	Reduce unnecessary traffic.
	Limit load size to reduce spillage.
	Minimize travel distances through appropriate site layout and design.
excavation and earthworks	Revegetate dry, exposed areas, when appropriate, to stabilize surfaces.
	Only remove secure covers in small areas and not all at once.
	All activities must be damped down, especially during dry weather.
stockpiles and storage mounds	Design the height and slope of the stockpiles to reduce wind entrainment. For example, a flat shallow stockpile will be subject to less wind turbulence than one with a tall conical shape.
	Keep stockpiles or mounds away from the site boundary, sensitive receptors and watercourses. If necessary, take into account the predominant wind direction to reduce the likelihood of affecting sensitive receptors.
	Seed, revegetate or turf long-term stockpiles to stabilize surfaces or use surface binding agents.
	Where possible, enclose stockpiles or keep them securely sheeted.
	Store fine material (such as under three millimeters in size) inside buildings or enclosures.
	Minimize drop heights to control the fall of materials.
tailings storage facility	Maintain active portion of the facility in a wet state.
	Apply water if monitoring indicated dust is an issue.
	Cover facility at closure with topsoil and revegetate.

Impact Analysis

Table C2.8-5 provides the results of the impact analysis for dust emissions and all combustion emissions. Dust control measures as outlined in Table C2.8-4 will be used to keep dust levels from exceeding applicable guidelines. The magnitude of the impact associated with dust and all other compounds are expected to be low and the geographic extents are expected to be local. The duration will be limited to the construction period and will be short term. Effects will be reversible once construction stops and cleared areas are revegetated. The frequency of the effect will be medium as construction activities will be intermittent. Based on the above criteria the environmental consequence is expected to be low.

Table C2.8-5 Residual Impact Classification for Key Question AQ-1

Parameter	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question AQ-1: What effect will construction emissions have on air quality in the receiving airshed?							
fugitive dust	negative	low[(a)]	local[(b)]	short-term	reversible	medium	low
combustion emissions	negative	low[(a)]	local[(b)]	short-term	reversible	medium	low

(a) Magnitude based on professional judgment and the assumption that construction effects will be lower than operational ones.

(b) Geographic extent based on professional judgement and the assumption that construction effects will be lower than operational ones.

Combustion (tailpipe) emissions are expected to be low in magnitude and local in geographic extent. There will be less vehicular traffic than during operations (operations emissions are quantified later in this section for reference) when the mine haul fleet will be active, and vehicle traffic will be intermittent. The duration is short term and effects are reversible once construction is over. Frequency is medium. As a result of the above criteria estimates, the environmental consequence is predicted to be low.

Prediction Confidence

The impact predictions are made using professional experience and judgment from other mining projects in similar environments. If mitigation for dust is carried out effectively, there is a high level of confidence in the predictions.

Monitoring

As construction is of short duration (two years) and the sources of emissions are intermittent with impact being near site, monitoring of fugitive emissions is not considered necessary.

C2.8.3.5 Key Question AQ-2

Key question AQ-2 is: What effect will emissions from operation of the proposed project have on air quality in the receiving airshed?

Figure C2.8-2 provides the linkage diagram for key question AQ-2. The effects of the proposed operations on the airshed within the LSA and RSA may have an effect on the social (people), aesthetic and fauna and flora environments. For example, ground-level particulate (dust) emissions could have the potential to affect human health as well as impact flora and fauna. Under some conditions, elevated particulate deposition could cause damage to crops. This linkage is valid and was carried through to an impact analysis.

Assessment Methods

The assessment of changes in ambient air quality was completed by using the following steps:

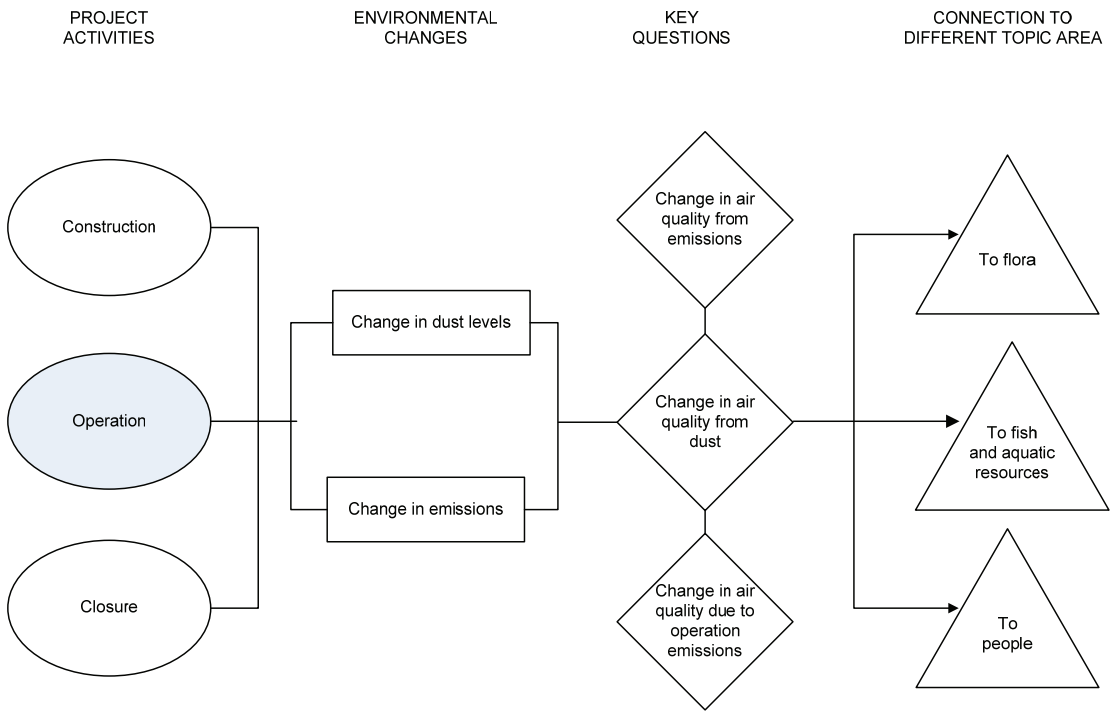
- Determining potential receptors.
- Determining the emissions generated by the project operations.
- Predicting the project-related ground-level concentrations that may occur at the identified receptors.
- Comparing predicted air concentrations with applicable guidelines.

The simulation of ground-level concentrations and deposition due to proposed activities was undertaken through the application of the United States Environmental Protection Agency's (US EPA) ISCST3 model. A detailed description of the modeling methodology is provided in Appendix C2.8-I.

Fugitive dust emissions were estimated using emission factors published by the US EPA in its AP42 document "Compilation of Air Pollution Emission Factors". The US EPA AP-42 emission factors are of the most widely used in the field of air pollution. Empirically derived predictive emission factor equations are available for vehicle-entrained dust from roadways, drilling and blasting and for materials handling operations. Wind erosion is calculated using a more detailed model to take into account the complexity of the source. Appendix C2.8-II provides a comprehensive review of the emission factors used for the fugitive dust sources while Appendix C2.8-III provides a summary of the source and emissions data used in the simulations.

Predicted concentrations were compared to applicable air quality standards (Section A2.7).

Figure C2.8-2 Linkage Diagram for Air Quality Key Question AQ-2



A summary of the emissions for the operation phase is provided in Table C2.8-6.

Table C2.8-6 Summary of the Routine Emissions for the Operation Phase

Source	Emissions (g/s)							
	SO_2	CO_2[l]	CO[m]	NO_2[n]	PM_{10} [o]	TSP [o]	H_2SO_4/ SO_3	VOC
115,000 Tonnes per Year Copper Processing Plant Emissions								
sulfuric acid plant	13.89	0.00	0.00	0.00	0.00	0.00	0.52	0.00
leach	2.33	1,780.77	0.00	0.00	0.00	0.00	0.00	0.00
iron remover 1	0.00	568.93	0.00	0.00	0.00	0.00	0.00	0.00
iron remover 2	1.93	96.45	0.00	0.00	0.00	0.00	0.00	0.00
iron remover 3	1.93	96.45	0.00	0.00	0.00	0.00	0.00	0.00
iron remover 4	1.93	96.45	0.00	0.00	0.00	0.00	0.00	0.00
CO dissolution scrubber	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00
copper precipitator 1	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
copper precipitator 2	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
copper precipitator 3	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fugitive Emission Sources								
materials handling	0.00	0.00	0.00	0.00	0.10	0.29	0.00	0.00
drilling	0.00	0.00	0.00	0.00	0.42	0.80	0.00	0.00
blasting	4.01	0.00	136.22	32.05	0.03	0.06	0.00	0.00
storage piles[p]	0.00	0.00	0.00	0.00	14.47	84.69	0.00	0.00
vehicle entrainment	0.00	0.00	0.00	0.00	8.67[k]	30.41[k]	0.00	0.00
crushing of limestone	0.00	0.00	0.00	0.00	0.62	0.68	0.00	0.00
vehicle emissions[a]	0.43[c]	1,289.00	7.38	5.16	8.88	8.88	0.00	0.00
pre-heater[b]	0.01	2.00	0.01	0.004	0.01	0.01	0.00	0.00
mixer settler and tank farm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	85.05
electrowining tankhouse	0.00	0.00	0.00	0.00	0.00	0.00	2.54	0.00

[a] Tailpipe emissions based on the maximum diesel fuel usage during 2019 of 15,045,000 liters per year.

[b] Emissions were calculated for 20 tonnes per year of diesel used.

[c] A 0.05 percent sulfur content in the fuel was assumed.

[d] g/s = grams per second.

[e] SO_2 = sulfur dioxide.

[f] CO_2 = carbon dioxide.

[g] CO = carbon monoxide.

[h] PM_{10} = inhalable particulate matter with a diameter of less than 10 micrograms.

[i] NO_2 = nitrogen dioxide.

[j] TSP = total suspended solids.

[k] Emissions from vehicle entrainment were calculated assuming a 80 percent control efficiency on the road surfaces.

[l] Some intermitted sources of CO_2 emissions consist of the acid plant startup (5,439 tpa), emergency generators (2,287 tpa) and the fire pump (8,552 tpa).

[m] The emergency generators (intermitted source) have a CO emissions of 0.88 g/s.

[n] The emergency generators (intermitted source) have a NO_x emissions of 10.34 g/s.

[o] The emergency generators (intermitted source) has a PM emissions of 0.12 g/s.

[p] The storage piles consist of the waste rock and low grade ore stockpiles, lime stockpile and the tailings. Emissions exclude rainy season. Rainy season was taken into account during simulations.

Some solid waste will be landfilled. The impact from the landfill sites will be due to the dust produced from wind erosion and vehicle activity, and potential decomposition gas produced by the waste.

Mitigation

The following mitigation measures will be implemented during the operation of the proposed project:

- Mill feed conveyors covered.
- Enclosed conveyor at the crushed ore bin.
- Emissions from the limestone crusher are directed to a bag house.
- Wet grinding will be implemented for the ROM material.
- A scrubber will be used for the sulfuric acid plant start-up conditions. Scrubber efficiency used in the model was based on information provided by the engineering team.
- Mitigation to keep sulfuric acid emissions from the tankhouse to below occupational health and safety levels may include: plastic beads spread on the electrolyte surface; chemical addition to the tankhouse to change the surface tension of the liquid.
- The control efficiency of a typical bag house ranges from 79 percent (hood only) to 99 percent (totally enclosed). It is not practical to accurately predict the actual bag filter efficiency from the proposed process, as this is largely linked to operating conditions. The thickness and the nature of the filter cake on the bag surface are important as this has a significant effect on the filter efficiency. The aging of the filter bags and frequency of cleaning also influence the overall efficiency. For the current study, the lower range (approximately 80 percent) control efficiency was assumed as a conservative approach, however, it is expected that the actual efficiency will be larger than this.

Results

Model simulations were undertaken to determine ground-level concentrations of the compounds described above. Averaging periods were selected to facilitate comparisons between predicted concentrations and applicable ambient air quality guidelines and standards. Average total daily deposition rates were also presented.

Maximum ground-level concentrations predicted to occur outside of the project footprint during normal operating conditions are given in Table C2.8-7. A comparison to applicable and reference standards/guidelines is also supplied in the table.

Table C2.8-7 Summary of the Highest Predicted Off-Site Ground-Level Concentrations

Parameter	Highest Predicted Concentration Off-Site [µg/m³]	Applicable [µg/m³]	Reference [µg/m³]		
		World Bank Group[a]	WHO[b]	DRC NMC	US EPA
Sulfur Dioxide (SO_2)[c]					
24-hour	100 (150)[c]	500	125	500	365
annual	25	100	50	100	80
Nitrogen Oxides (NO_2)					
24-hour	10	200	-	200	-
annual	0.2	100	40	100	100
Particulate Matter (PM_{10})					
24-hour	420	500	-	500	150
annual	100	100	-	100	50
Carbon Monoxide (CO)					
1-hour	50	-	-	-	40,000
Volatile Organic Compounds (VOC)					
24-hour	2,600	-	-	-	-
Acid Mist (SO_3/H_2SO_4)					
1-hour	120	-	-	-	-

[a] Thresholds outside project property boundary – World Bank Environment, Health and Safety Guidelines – Mining and Milling – Open Pit. World Bank 1995a.

[b] Pollutant concentration limit at property boundary. World Bank 1998. Pollution Prevention and Abatement Handbook.

[c] Value given in brackets for the SO_2 predicted concentrations is for the start-up of the sulfuric acid plant.

Sulfur Dioxide (SO_2)

Based on a copper production rate of 115,000 tonnes per year, the predicted ground level 24-hour and annual SO_2 concentrations are within all applicable and references standards/guidelines for all averaging periods.

During start-up conditions at the sulfuric acid plant, the SO_2 emissions are predicted to increase. As a result the maximum 24-hour ground-level concentration is predicted to be 150 micrograms per cubic meter off site. This is still within the World Bank and DRC standards/guidelines.

No figure is presented for SO_2 concentrations as the spatial extent is small and the values are less than guidelines.

Nitrogen Dioxide (NO_2)

Predicted NO_2 ground-level concentrations beyond the site boundary are within all applicable standards/guidelines for all averaging periods.

No figure is presented for NO_2 concentrations for the same reason as discussed for SO_2.

Inhalable Particulate Matter (PM_{10})

The highest daily ground-level concentrations (assuming 80 percent control efficiency on the unpaved road surfaces) are predicted to be 420 micrograms per cubic meter directly off-site in the dry season (Figure C2.8-3). This concentration is in line with the World Bank guideline of 500, but exceeds the US EPA reference guideline of 150. An annual average concentration (that assumes a six month wet season) of 100 micrograms per cubic meter was predicted just beyond the plant boundary (Table C2.8-7; Figure C2.8-4). This is in line with the World Bank and DRC guideline of 100 micrograms per cubic meter.

Carbon Monoxide (CO)

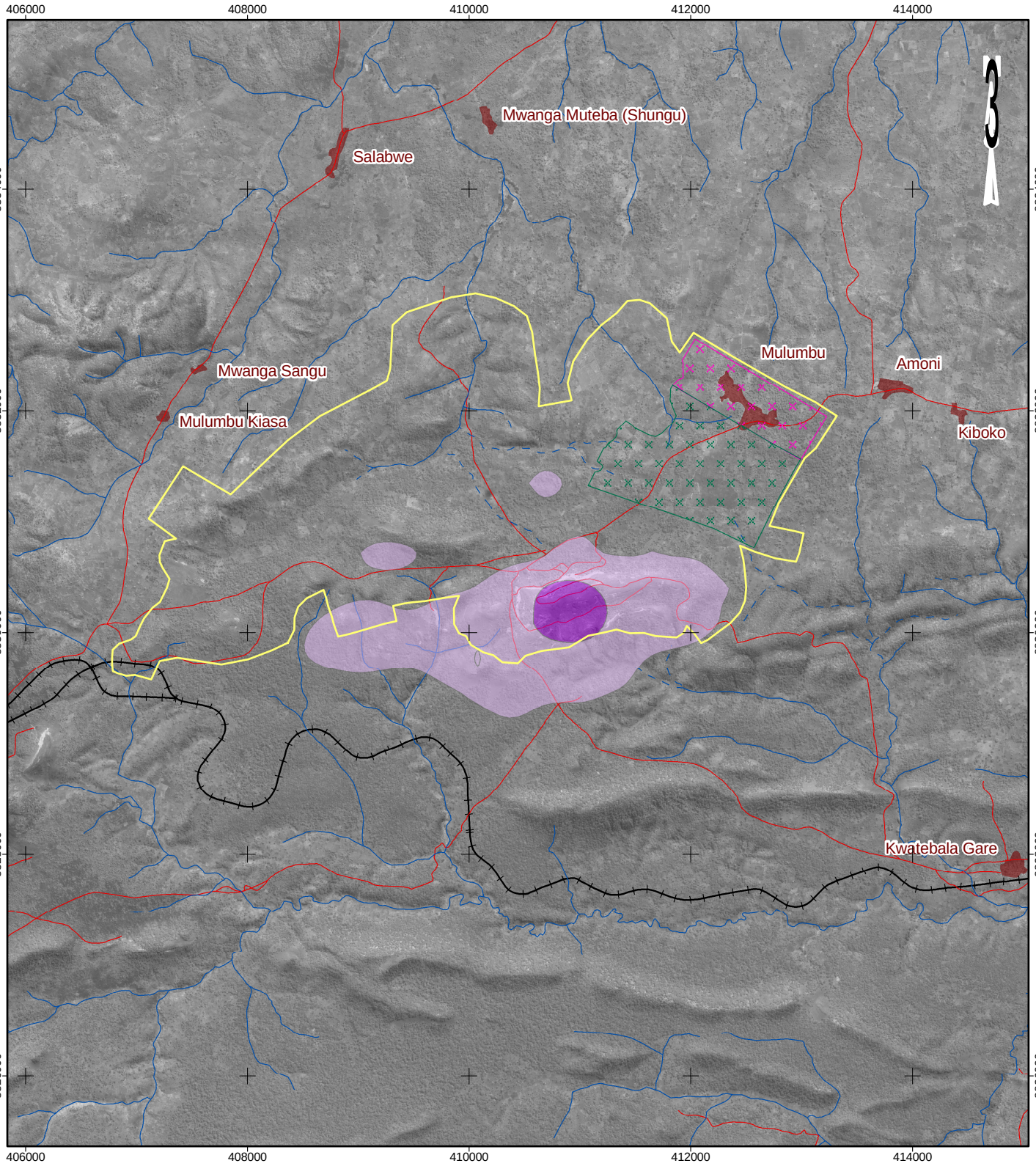
Predicted hourly carbon monoxide ground-level concentrations directly off site (due to blasting, process activities and vehicle tailpipe emissions) are within all applicable and reference standards/guidelines.

Carbon Dioxide (CO_2)

TFM proposes to use electric power to power the plant. Therefore, greenhouse gas emissions will be less than if diesel or other fuels were used to power the plant. The estimated carbon dioxide direct emissions from the mining operation and processing plant would be about 0.14 million metric tons per year (averaged over the period 2009 to 2018). This should be seen in the perspective of the annual DRC, Africa and global emission rate of GHGs, which is approximately two million metric tons, 861 million metric tons and 26,778 million metric tons, respectively expressed as carbon dioxide (CO_2) equivalent (CO_2E) (Marland, et al. 2006). The mine's emissions therefore contribute approximately 8.09 percent of the DRC GHG emissions and 0.02 percent of Africa's total GHG emissions. This is equivalent to 0.0005 percent of global GHG emissions.

Volatile Organic Compounds (VOC)

The solution extraction (SX) facility will consist of a single circuit comprising three extractions, two stripping and one wash stage. Parallel streams of high-grade (HG) and low-grade (LG) pregnant leach solutions will be fed to the extraction stages for copper recovery. The SX organic stream will comprise 29 percent by volume diluent Shellsol 2325 (or equivalent) and 70 percent by volume of extractant – Lix 984N (or equivalent). The plant will contain an operating inventory of approximately 2,500 cubic meters of organic. The design operating temperature for SX is 40 degrees Celsius. The VOC emissions from the plant were calculated to be 1,240 tonnes per year, using methodologies proposed by the National Pollutant Inventory (1999) (see Appendix C2.8-IV).



LÉGENDE / LEGEND

- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- EMPREINTE AU SOL / FOOTPRINT
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PRÉDICTIONS PM_{10} / PM_{10} PREDICTIONS

- 150 µg/m³
- 500 µg/m³

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY

RÉFÉRENCE / REFERENCE

Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

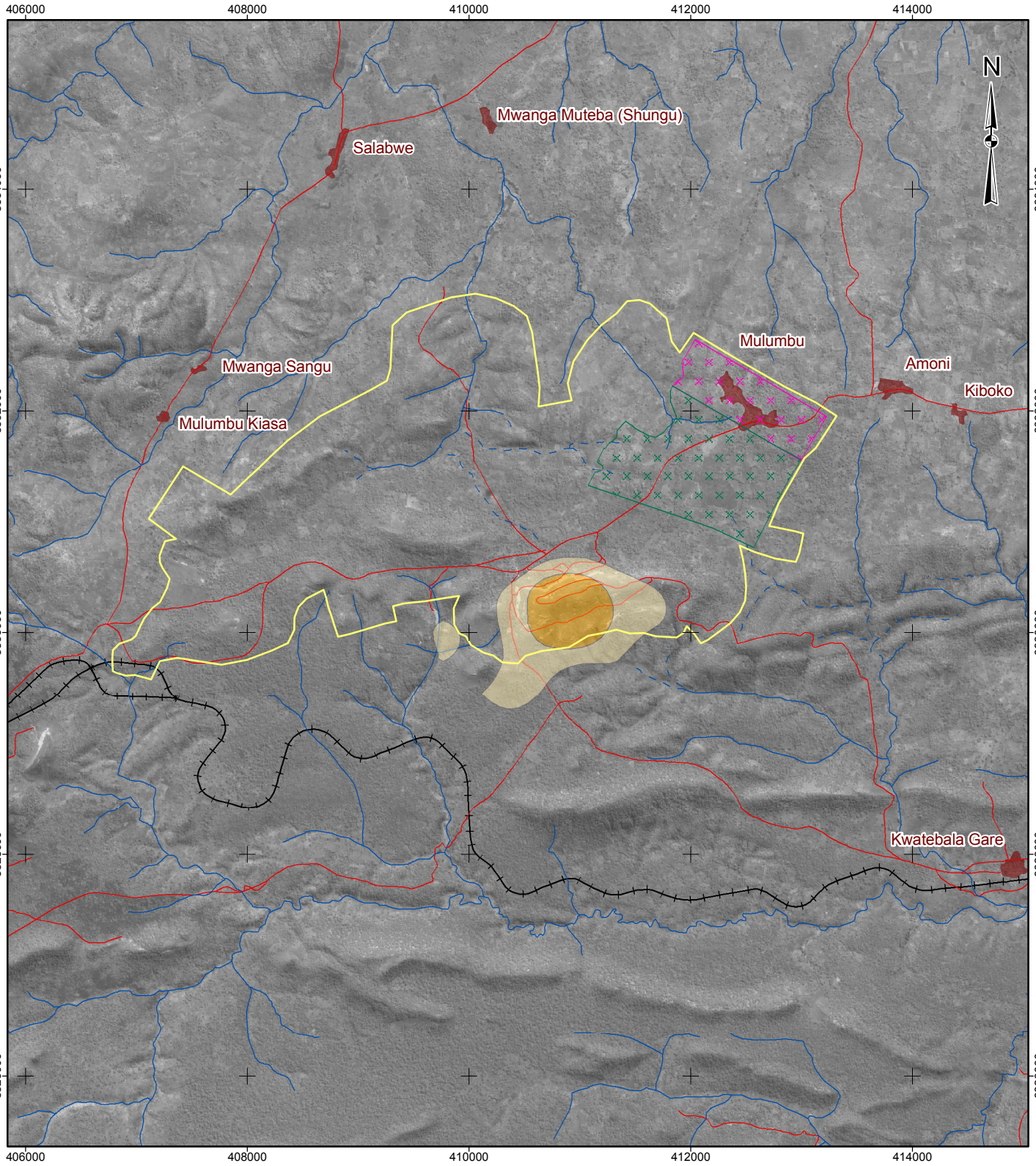
PRÉDICTIONS JOURNALIÈRES DU SCÉNARIO
PROJET RÉALISÉ SUR LE CAS DU PM_{10} /
HIGHEST DAILY PROJECT PM_{10} PREDICTIONS

Golder Associates
Calgary, Alberta

N° projet / project no. 05-1334-035			Échelle telle qu'indiquée / Scale as Shown	REV. 0
DESSIN / DESIGN	GU	22 Jun. 2006		
SIG / GIS	AC	28 Mar. 2007		
VÉRIFIÉ / CHECK	MR	12 Jul. 2006		
APPROUVÉ / REVIEW	MR	31 Jul. 2006		

FIGURE: C2.8-3

Project I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\mxd\Tenke_ESIA\Volume_C\FigureC2.8-3_Dy_Application_PM10.mxd - Plot I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\pdf\Tenke_ESIA\Volume_C\FigureC2.8-3_Dy_Application_PM10.pdf



ÉCHELLE / SCALE 1:50000 KILOMÈTRES / KILOMETERS

LÉGENDE / LEGEND

- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- EMPREINTE AU SOL / FOOTPRINT
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PRÉDICTIONS PM_{10} / PM_{10} PREDICTIONS

- 50 µg/m³
- 100 µg/m³

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY

RÉFÉRENCE / REFERENCE

Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

PRÉDICTIONS ANNUELLES DU SCÉNARIO PROJET RÉALISÉ SUR LE CAS DU PM_{10} / HIGHEST ANNUAL PROJECT PM_{10} PREDICTIONS

Golder Associates
Calgary, Alberta

N° projet / project no. 05-1334-035			Échelle telle qu'indiquée / Scale as Shown	REV. 0
DESSIN / DESIGN	GU	22 Jun. 2006		
SIG / GIS	CW	16 Feb. 2007		
VÉRIFIÉ / CHECK	MR	12 Jul. 2006		
APPROUVÉ / REVIEW	MR	31 Jul. 2006		

FIGURE: C2.8-4

Project I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\mxd\Tenke_ESIA\Volume_C\FigureC2.8-4_Yr_Application_PM10.mxd - Plot I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\pdf\Tenke_ESIA\Volume_C\FigureC2.8-4_Yr_Application_PM10.pdf

Ontario has developed a health-based ambient air quality criterion (2,600 micrograms per cubic meter – 24-hour average) and a health-based interim Point of Impingement standard (7,800 micrograms per cubic meter – 30-minute average) for mineral spirits and, in particular, light aliphatic solvent petroleum naphtha which has the same chemical properties as Shellsol.

The daily ground level concentrations directly off site (2,600 micrograms per cubic meter) were within the Ontario ambient health air quality criterion.

The 30-minute predicted ground level concentrations, based on the Point of Impingement standard (odor guideline) from Ontario for mineral spirits, extends approximately 2.3 kilometers east to west (approximately 600 meters west of the plant).

Acid Mist (H_2SO_4/SO_3)

The Office of Environmental Health Hazard Assessment (OEHHA) provide an acute health screening level for acid mist of 120 micrograms per cubic meter.

Based on a copper production rate of 115,000 tonnes per year, the predicted ground level 1-hour acid mist concentrations of 120 micrograms per cubic meter (directly offsite) are within the OEHHA acute screening level. (A detailed discussion on the acid mist emission calculations is given in Appendix C2.8-V)

During start-up conditions at the sulfuric acid plant, the acid mist emissions are predicted to increase. As a result the maximum 1-hour ground-level concentration is predicted to be 120 micrograms per cubic meter further off site. This is still within the OEHHA acute health screen level.

Impact Analysis

The residual impact classification summary for the compounds assessed in the operation scenario is provided in Table C2.8-8. The environmental consequence is expected to be low for SO_2, NO_2, PM_{10} (24-hour), CO, VOCs, odor and acid mist. The environmental consequence is predicted to be moderate for GHGs in terms of the contribution to the DRC and PM10 (annual) where 80 percent control efficiency is applied to unpaved road surfaces and the bag house.

Table C2.8-8 Residual Impact Classification for Key Question AQ-2

Parameter	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question AQ-2: What effect will emissions from operation of the proposed project have on sensitive receptors?							
SO_2 24-hour	negative	low	local	medium-term	reversible	high	low
SO_2 annual	negative	low	local	medium-term	reversible	high	low
NO_2 24-hour	negative	low	local	medium-term	reversible	high	low
NO_2 annual	negative	low	local	medium-term	reversible	high	low
PM_{10} 24-hour	negative	low	local	medium-term	reversible	high	low
PM_{10} annual	negative	low	local	medium-term	reversible	high	low
CO 1-hour	negative	low	local	medium-term	reversible	high	low
GHG emissions	negative	low[(a)]	regional	medium-term	reversible	high	moderate
VOC (naphtha 24-hour)	negative	low	local	medium-term	reversible	high	low
odor	negative	low	local	medium-term	reversible	high	low
acid mist	negative	low	local	medium-term	reversible	high	low

(a) Relative to the DRC's current emissions.

Prediction Confidence

It is important to note the limitations and assumptions on which the assessment was based. The most important of these include the following:

- Assumptions were made for the bulk density of material, silt content and particle size distribution to estimate wind erosion emissions as this information was not available for the current study.
- Assumptions were made on the parameters of the bag house facility as no information could be provided for this source.
- The diameter and exit velocity for the copper removal vents were estimated as this information was not available.
- The assessment of PM_{10} was based on 80 percent control efficiency on unpaved road surfaces.
- PM_{10} and TSP emissions were calculated for dry conditions and thus would be negligible during wet conditions.

- Although a scrubber will be in place for the start-up of the sulfuric acid plant, double the emissions of the routine operations was assumed for these conditions.

Monitoring

Given the potential for significant PM_{10} concentrations due to the proposed development, ambient monitoring should be established during operations to measure these concentrations at the site and in the vicinity of human settlements.

The monitoring of source emissions at the processing facility would assist in the establishment of a comprehensive emissions inventory to aid in future dispersion modeling exercises. If this confirmatory monitoring indicates that emissions vary significantly from the current estimates, additional monitoring and modeling may be warranted for those emissions.

Monitoring is more fully described in Section D3.13.

C2.8.3.6 Key Question AQ-3

Key question AQ-3 is: What effect will closure emissions have on air quality in the receiving airshed?

Linkage Evaluation

Closure activities would normally consist of demolition of the processing plant and rehabilitation of the tailings storage facility and waste rock facilities. Demolition activities result in a potential for dust generation and therefore the linkage is valid (Figure C2.8-1).

Vehicular activity will occur during closure although traffic will be much less than during operation. The linkage is valid.

Assessment Methods

Due to the intermittent nature of the closure phase operations and the type of emissions from the demolition activities (mainly large particulate matter, with fallout close to the site), a qualitative assessment was undertaken using professional judgment.

Mitigation

Dust control measures which may be implemented during the closure phase are outlined in Table C2.8-4 (as for construction activities).

Impact Assessment

Dust created by demolition activity will vary substantially from day to day depending on the level of activity. Overall, the magnitude of this effect is considered to be low (Table C2.8-9). As the particulate matter consists of large matter the fallout is normally close to the activity and thus the geographic extent will be local. Duration is expected to be short term, effects are reversible and the frequency is medium. The environmental consequence is therefore predicted to be low.

Table C2.8-9 Residual Impact Classification for Key Question AQ-3

Parameter	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question AQ - 3: What effect will closure emissions have on air quality in the receiving airshed?							
fugitive dust	negative	low[(a)]	local[(b)]	short-term	reversible	medium	low
combustion emissions	negative	low[(a)]	local[(b)]	short-term	reversible	medium	low

(a) Magnitude based on professional judgment and the assumption that closure effects will be lower than operational ones.

(b) Geographic extent based on professional judgment and the assumption that closure effects will be lower than operational ones.

Concentrations due to tailpipe emissions will be low in magnitude and relatively localized. The environmental consequence is therefore predicted to be low.

Prediction Confidence

The impact predictions are made using professional experience and judgment from other mining projects in similar environments. If mitigation for dust is carried out effectively, there is a high level of confidence in the predictions.

Monitoring

As closure operations are of short duration and the sources of emissions are intermittent with impact being near site, monitoring of fugitive emissions is not necessary.

C2.8.3.7 Key Question AQ-4

Key question AQ-4 is: How can the project have a long-term positive effect on the receiving airshed?

Linkage Evaluation

As most air quality effects will cease upon closure of the project there are few measures that can be taken to provide long-term improvements to local air

quality. However, benefits that could accrue from project activities or offsets include:

- Improvements to the local electrical grid and establishment of a local power distributor. This would lead to less dependence on wood and charcoal for cooking and better indoor air quality.
- Improvements to roads. Local and regional roads are in a poor state of repair. Improvements made for the project would have an ancillary benefit in terms of reducing dust emissions and improving travel times and fuel efficiency.
- Promotion of simple, fuel efficient stoves for household use would lead to an improvement in indoor air quality.
- Promotion of agroforestry and harvesting of non-timber forest products would lead to less deforestation as well as some tree planting and would aid in carbon sequestration.

These linkages are all valid. However, a linkage diagram is not presented.

Assessment Methods

A qualitative approach was taken for the assessment of sustainability. The sustainability actions described below are potential courses of action that may or may not receive community support. Key to the sustainability approach is that the communities will be engaged to determine which ideas are best suited to local needs.

Mitigation

Local Electrical Grid and Distributor

The power supply for the processing plant will come from a hydroelectric power plant. This plant will be upgraded, in part, to provide service to the project. This in and of itself will be a sustainable benefit as the upgrade will allow other industry to use renewable energy as opposed to fossil fuels.

The power distribution network, including refurbishment of existing substations and construction of a new transmission line to the Kwatebala processing plant, will be improved. Electricity likely will be provided to growth centers at Fungurume and Tenke to focus growth in a controlled manner. This electrical distribution could be expanded under community development programs to include local residences. While currently few residents could afford to pay for electricity, this will change as direct and indirect jobs are created. Over time, consideration could be given to establishment of a private electrical distribution utility that could provide electricity, first to the growth centers and the permanent

village, and later to the public as they become more affluent. This utility could then persist beyond the life of the mine.

Improvements to Roads

The roads within and adjacent to the concession are in poor condition (Section B2.13). The TFM project will include upgrading some portions of the National Road Number 1, as well as the Fungurume bypass road. This will have a positive effect on the users of these roads, and could result in fuel efficiencies. Currently, the National Road Number 1 is in such bad condition that traffic is very slow. Should sections of the roads be paved, such as the section that passes through Fungurume, a long-term benefit to residents could result. Treating the surface of this section would reduce dust emissions, provide residents with a better walking surface and eliminate potholes that are breeding grounds for malarial mosquitoes.

Consideration could also be given to establishment of a small business to maintain project roads on the concession. After closure, this company could continue its maintenance activity if the local and regional economies could support a tax base to pay for such services by that time.

Household Stoves

Indoor air quality is poor within the concession due to the use of wood and charcoal for cooking (Section B2.8). Incomplete combustion can range from 80 to 90 percent, with carbon monoxide and other compounds being produced that can be significant health hazards (Smith 2005). The exposure to these harmful substances is highest for women and children. The use of simple but efficient stoves, which vent to the outside, could have a benefit to these populations. Provision of stoves to the communities as gifts would not be sustainable. Rather, a small business could be encouraged to produce stoves for sale to TFM. This business could then develop a market within the local communities.

Promotion of Agroforestry and Non-Timber Forest Products

Agroforestry can be defined as “the deliberate growing of woody perennials on the same unit of land as agricultural crops and/or animals, either in some form of spatial mixture or sequence” (Nair 1993). Non-timber forest products (NTFP) include all biological materials, other than timber, that are taken from forests for human use (DeBeer and McDermott 2002). This may include foods, medicines, spices, essential oils, resins, latexes, ornamental plants, wildlife, fuelwood and other raw materials. As discussed in the flora assessment (Section C3.1), agroforestry initiatives and increased use of non-timber forest products would promote the planting of trees and therefore carbon sequestration.

Impact Analysis

The scoring for the above sustainability actions, as presented in Table C2.8-10, shows that the proposed actions could have moderate sustainability consequences. Discussion with community leaders and local non-governmental organizations (NGOs) will be necessary to determine the best course of action.

Table C2.8-10 Summary of Sustainability Assessment for Air Quality Key Question AQ-4

Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key question AQ-4: How can the project have a long-term positive effect on the receiving airshed?				
Local Electricity Distribution				
moderate	half the community	long-term	medium	moderate
Improvements to Road System				
moderate	half the community	long-term	medium	moderate
Household Stoves				
moderate	half the community	long-term	medium	moderate
Non-timber Forest Products (NTFP)				
moderate	half the community	long-term	low	moderate

Prediction Confidence

Results from improvements to the electrical and road systems can be predicted with confidence. However; it is unknown how receptive the local population would be in adopting new stoves or methods in land management and use. The success of an agroforestry project and the promotion of using non-timber forest products (NTFP) would be largely dependent upon non-governmental organizations (NGO) working with the communities. A key to success would be the support and involvement of village chiefs or key individuals within the community. The confidence in predicting the success of the sustainability initiatives is low, but the consequence of success may justify the effort and cost involved.

Monitoring

A monitoring and evaluation program will need to be developed and implemented once the exact nature and feasibility of the sustainability efforts are known. The monitoring program will need to assess the success and effectiveness of the proposed sustainability programs. The factors that should be considered in the monitoring program include:

- Number of households with electricity.

- Kilometers of road improvements made.
- Areas under forest.
- Success rate for small businesses in road maintenance and stove production.
- Number of households with stoves.
- Number of individuals or communities participating in the agroforestry and NTFP programs.

C2.8.4 Cumulative Effects Assessment

As no other mines are within the airshed of the proposed project, the cumulative effects assessment will deal with TFM activities only. No interaction is expected to occur with the nearest existing mine, the Kakanda Mine, that is 21 kilometers to the southeast. Emissions (haul fleet) from development of the Goma and Fwaulu pits also were assessed for the cumulative effects analysis.

Key question AQ-$1_{(ce)}$ is: What effect will cumulative operations have on air quality in the receiving airshed?

Key Question

The expanded project is anticipated to result in changes to air emissions from construction, operation and closure activities of the mine (Table C2.8-11).

Table C2.8-11 Key Question for Cumulative Effects to Air Quality

Impact Assessment	
Key question $AQ_{(ce)}$-1:	What effect will cumulative operations have on air quality in the receiving airshed?

Linkage Evaluation

The cumulative effects assessment consists of the proposed operating conditions at the mines, the potential expansion to 400,000 tonnes per year copper production (a 200,000 tonnes per year processing plants at Kwatebala and Fungurume respectively) and the activity at the limestone quarry. No other known projects in the vicinity of the concession are reasonably foreseeable.

Air assessment issues related to the future cumulative effects include:

- Emissions from the operation of the future project expansion, including Goma and Fwaulu, (cumulative impacts) will potentially result in

increased ambient air concentrations at sensitive receptors (i.e., human settlements and agricultural land).

Assessment Criteria

The effects of the proposed cumulative operations on the airshed within the LSA and RSA will affect the social, aesthetic and fauna and flora environments (Figure C2.8-1).

Assessment Methods

The cumulative assessment included modeling of emissions from two 200,000 tonnes per year plants as well as tailpipe emissions from haul fleets at Kwatebala, Goma and Fwaulu. The largest haul fleets estimated to be required during the life of each pit were used to provide a conservative estimate of effects. Due to large uncertainties associated with the emissions from an expanded project it is difficult to estimate the ground-level concentrations with any certainty or objectivity. The ground level concentrations of combustion compounds such as sulfur dioxide, nitrogen dioxide and carbon monoxide will likely increase; however, the 400,000 tonnes per year operation will comprise a number of mine pits and two processing facilities. This configuration will result in lower ground-level concentrations than would result if there was one central processing facility and a single mine pit. Irrespectively the increase in fuel consumption and airborne emissions from the processing plants will offset the lower concentrations to a certain degree. It is possible that the ground-level concentrations in the communities surrounding the facilities will either go down or up depending on their location with respect to the processing facilities and the phase that the mining is in for a given year. The assessment of changes in ambient air was completed for the cumulative effects of SO_2 emissions from the two plants and PM_{10} impacts from all exposed stockpile areas. The cumulative mining operations were also included and ground-level concentrations of NO_2 and CO_2 were predicted.

Mitigation

Mitigation measures that will be implemented during future operations have been outlined under the operation phase (Section C.2.3.5).

Results

Model simulations were undertaken to determine ground-level concentrations of the compounds described above. Maximum ground-level concentrations predicted to occur during cumulative operating conditions are given in Table C2.8-12. A comparison to applicable and reference standards/guidelines is also supplied in the table.

Table C2.8-12 Summary of the Highest Predicted Off-Site Ground-Level Concentrations - Cumulative Operations

Parameter	Highest Predicted Concentration Off-Site	Applicable	Reference		
		World Bank Group[a]	WHO[b]	DRC NMC	US EPA
Sulfur Dioxide (SO_2)					
24-hour	365	500	125	500	365
annual	100	100	50	100	80
Nitrogen Oxides (NO_2)					
24-hour	10	200	-	200	-
annual	4	100	40	100	100
Particulate Matter (PM_{10})					
24-hour	500	500	-	500	150
annual	100	100	-	100	50
Carbon Monoxide (CO)					
1-hour	100	-	-	-	40,000

[a] Thresholds outside project property boundary – World Bank Environment, Health and Safety Guidelines – Mining and Milling – Open Pit. World Bank 1995a.

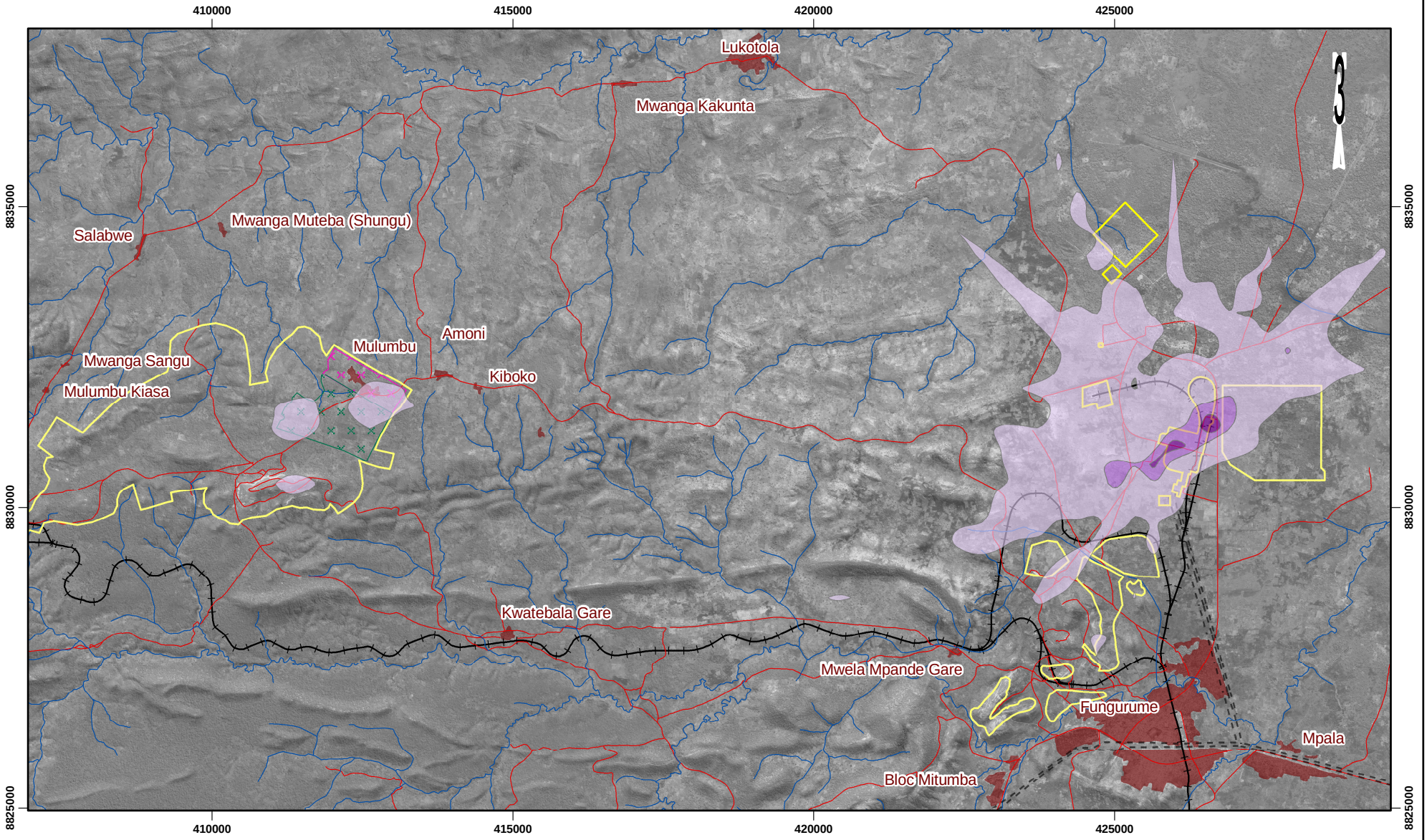
[b] Pollutant concentration limit at property boundary. World Bank 1998. Pollution Prevention and Abatement Handbook.

Sulfur Dioxide (SO_2)

Based on the copper production rate of 400,000 tonnes per year, the predicted 24-hour ground-level concentrations outside the property boundary are predicted to be within the World Bank and DRC standards/guidelines (Figure 2.8-5). The 24-hour ground-level concentrations, however, exceed the reference WHO guidelines of 125 and 50 respectively. The annual ground-level concentrations meet the WHO guideline of 100 but exceed the US EPA guidelines of 80 (Figure C2.8-6). It must be recognized, however, that the processing of additional ore types associated with the 400,000 tonnes per year case will certainly not require the same amount of sulfuric acid production per tonne of ore processed. It may go up or down, depending on the alkalinity of the ore, the abundance of sulfide mineralization in the ore, and the processing methods selected in the future. Future alternative analyses will factor in ambient air quality as a primary concern in selecting future processing methods, locations, and emissions controls systems.

Nitrogen Dioxide (NO_2)

Predicted NO_2 ground-level concentrations beyond the site boundary are within all applicable standards/guidelines for all averaging periods.



LEGENDE / LEGEND

- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- EMPREINTE AU SOL / FOOTPRINT
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PRÉDICTIONS SO_2 / SO_2 PREDICTIONS

- 125 µg/m³
- 365 µg/m³
- 500 µg/m³

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY

2 0 2

ÉCHELLE 1:90000 KILOMÈTRES
SCALE 1:90000 KILOMETERS

RÉFÉRENCE / REFERENCE

Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

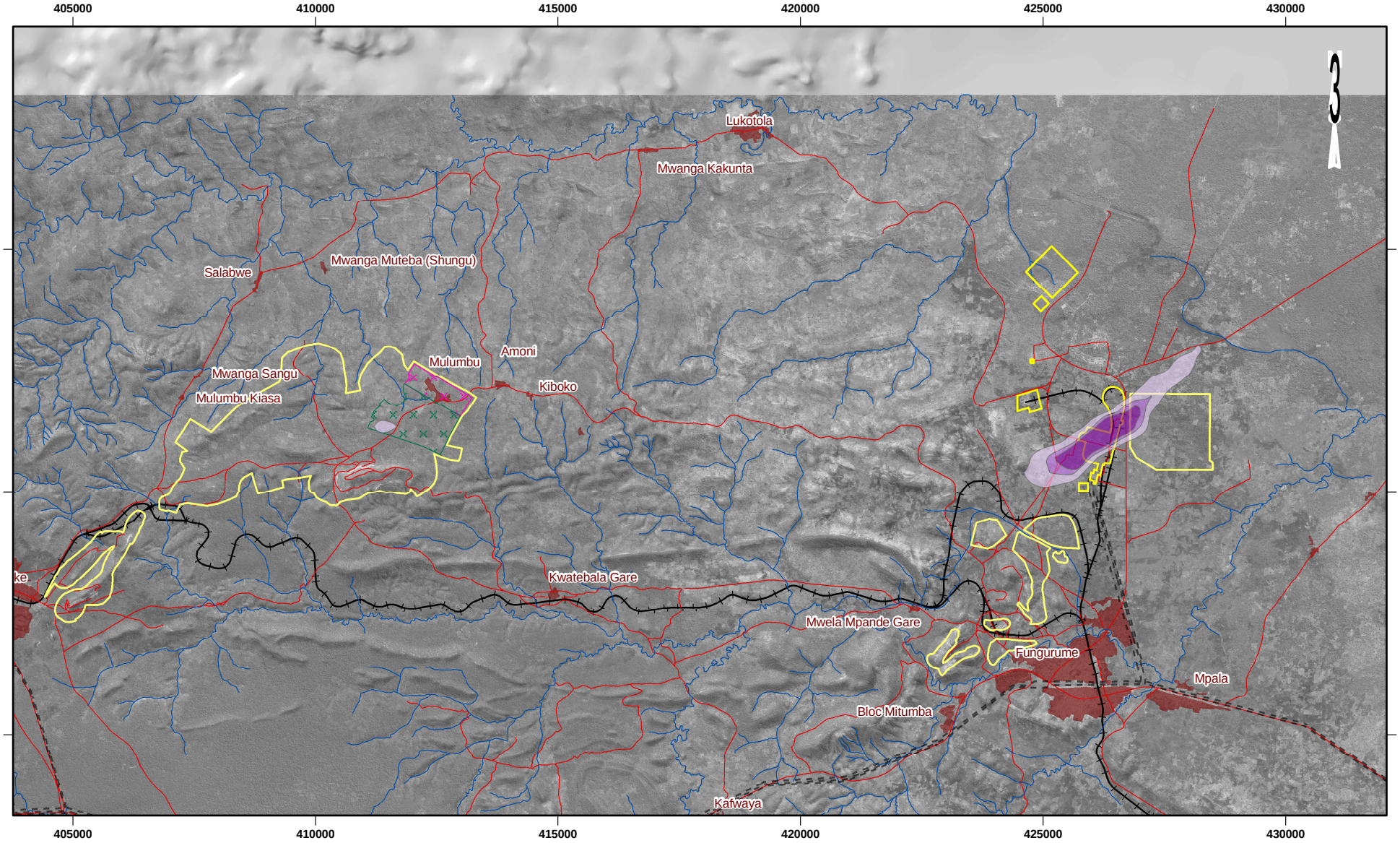
PRÉDICTIONS JOURNALIÈRES CUMULATIFS SUR LE CAS DU SO_2 / DAILY CUMULATIVE SO_2 PREDICTIONS

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	GU	18 Aug. 2006		
SIG / GIS	AC	28 Mar. 2007		
VÉRIFIÉ / CHECK	MR	16 Feb. 2007		
APPROUVÉ / REVIEW	MR	16 Feb. 2007		

FIGURE: C2.8-5

Project: I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\mxd\Tenke_ESIA\Volume_C\FigureC2.8-6_Yr_Cumulative_SO2.mxd Plot: I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\pdf\Tenke_ESIA\Volume_C\FigureC2.8-6_Yr_Cumulative_SO2.pdf



LEGENDE / LEGEND

- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- EMPREINTE AU SOL / FOOTPRINT
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PRÉDICTIONS SO_2 / SO_2 PREDICTIONS

- 50 µg/m³
- 80 µg/m³
- 100 µg/m³

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY

2 0 2

ÉCHELLE 1:112500 KILOMÈTRES
SCALE 1:112500 KILOMETERS

RÉFÉRENCE / REFERENCE

Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

PRÉDICTIONS ANNUELLES CUMULATIFS SUR LE CAS DU SO_2 /
ANNUAL CUMULATIVE SO_2 PREDICTIONS

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	GU	18 Aug. 2006		
SIG / GIS	AC	28 Mar. 2007		
VÉRIFIÉ / CHECK	MR	16 Feb. 2007		
APPROUVÉ / REVIEW	MR	16 Feb. 2007		

FIGURE: C2.8-6

Carbon Monoxide (CO)

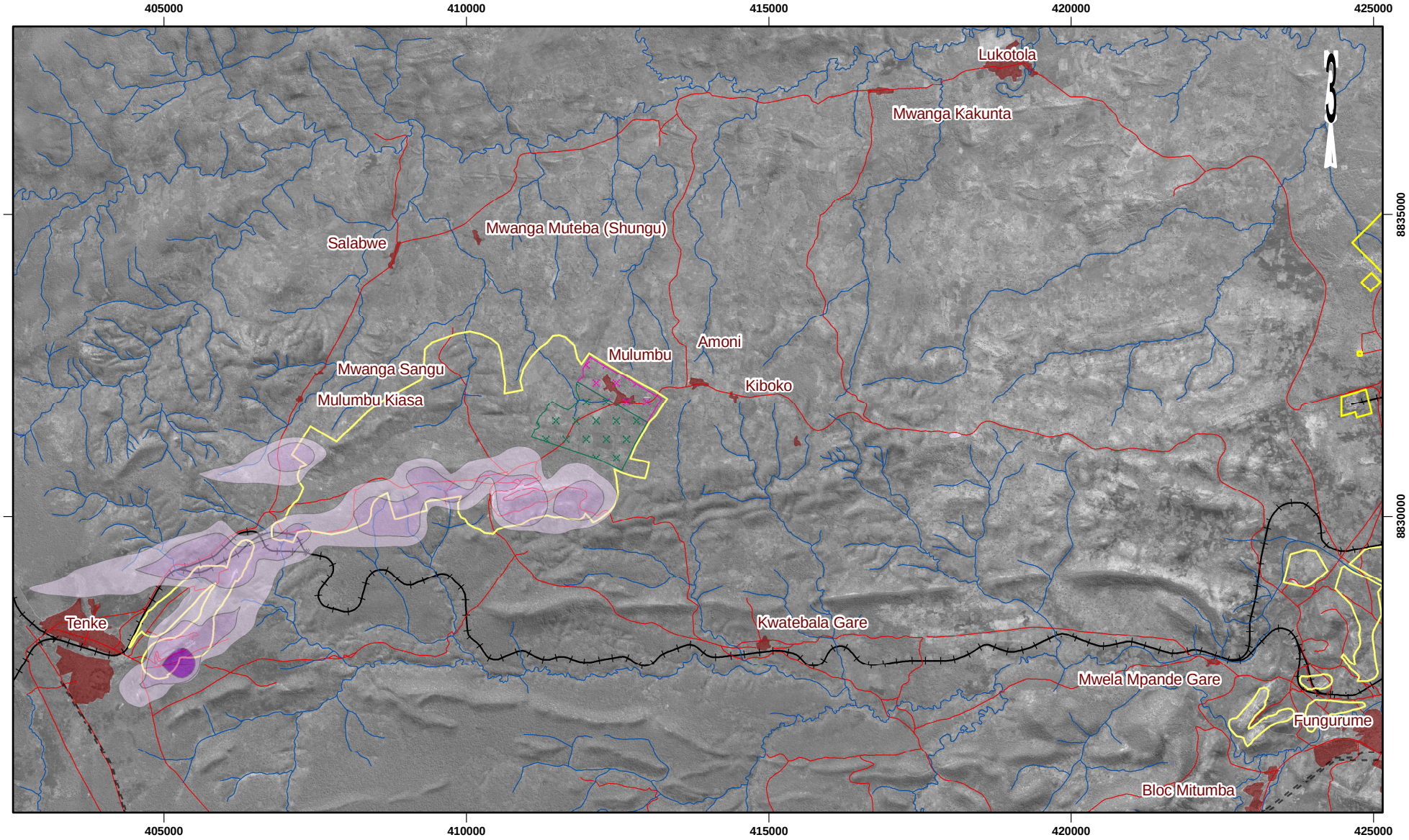
CO emissions area also highly dependent on the method of mineral processing selected. It is presently not known what method of mineral processing will be implemented for the 400,000 tonnes per year case. Future alternative analyses will factor in ambient air quality as a primary concern in selecting future processing methods, locations, and emissions controls systems. The predicted hourly carbon monoxide ground-level concentrations directly off site, however, (due to blasting, process activities and vehicle tailpipe emissions) are within all applicable and reference standards/guidelines.

Inhalable Particulate Matter (PM_{10})

If all mineral processing methods in the cumulative case will be the same type as proposed for the Kwatebala processing plant (which in not likely, due to ore differences) the highest daily ground-level concentrations (500) are predicted to exceed the reference US EPA guideline of 150, but are in line with the applicable World Bank guideline and DRC standard of 500 (Table C2.8-12; Figure C2.8-7 outside the facility boundary. An annual average concentration of 100 micrograms per cubic meter was predicted beyond the plant boundary (Figure C2.8-8). This is in line with the World Bank guideline of 100 micrograms per cubic meter.

Carbon Dioxide (CO_2)

If all mineral processing methods in the cumulative case will be the same type as proposed for the Kwatebala processing plant (which in not likely, due to ore differences) the predicted average carbon dioxide (CO_2) direct emissions from the mining operation and process plant would be about 0.29 million metric tons per year (averaged over the period 2009 to 2018). This should be seen in the perspective of the annual DRC, Africa and global emission rate of GHG, which is approximately two million metric tons, 861 million metric tonnes and 26,778 million metric tonnes, respectively expressed as carbon dioxide equivalent (Marland et al, 2006). The mine CO_2 emissions therefore contribute approximately 16.19 percent of the DRC GHG emissions and 0.03 percent of Africa's total GHG emissions. This would only be 0.001 percent of the global GHG emissions.



LEGENDE / LEGEND

- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- EMPREINTE AU SOL / FOOTPRINT
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PRÉDICTIONS PM_{10} / PM_{10} PREDICTIONS

- 70 µg/m³
- 150 µg/m³
- 500 µg/m³

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY

2 0 2

ÉCHELLE 1:90000 KILOMÈTRES
SCALE 1:90000 KILOMETERS

RÉFÉRENCE / REFERENCE

Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

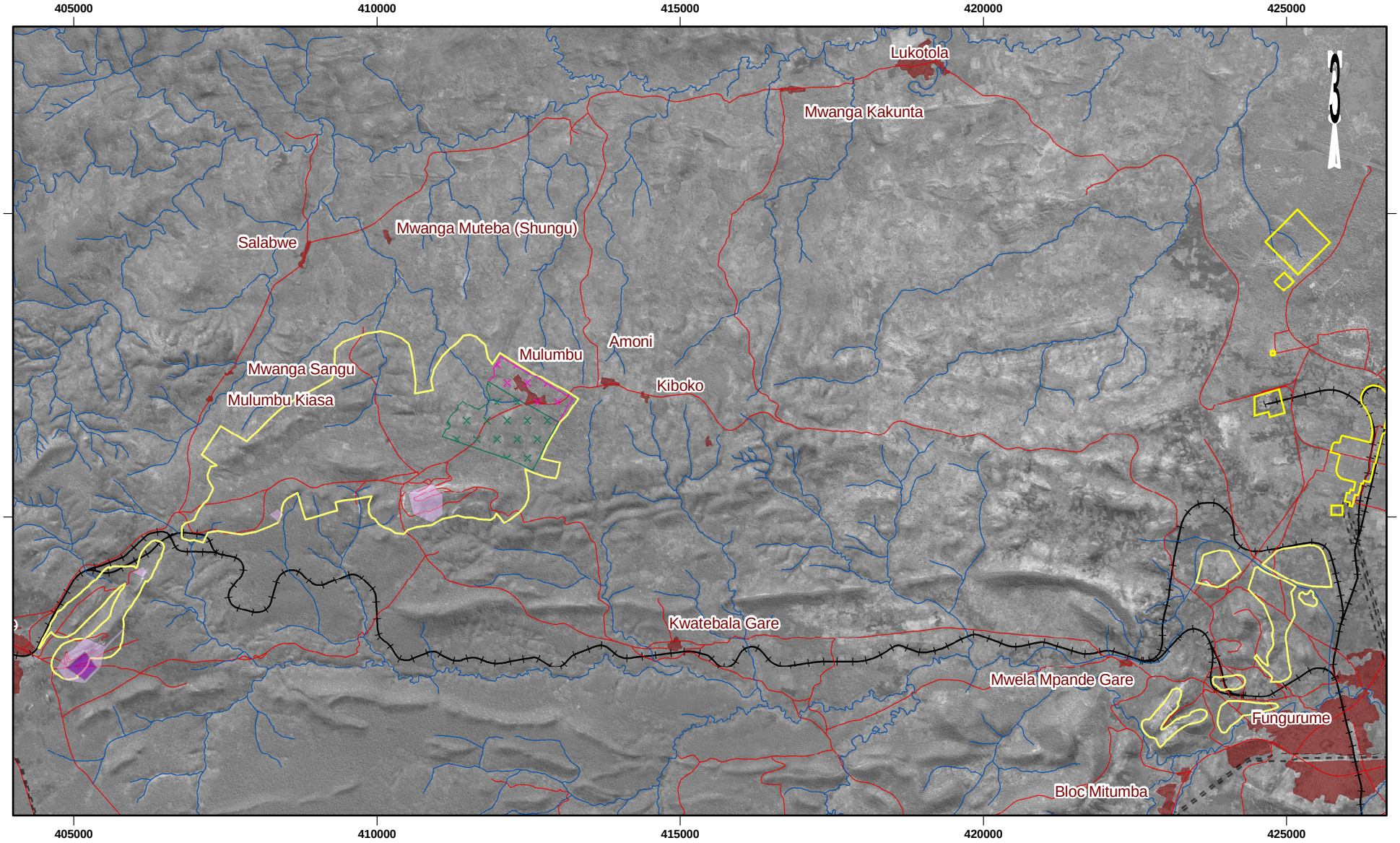
PRÉDICTIONS JOURNALIÈRES CUMULATIFS SUR LE CAS DU PM_{10} / DAILY CUMULATIVE PM_{10} PREDICTIONS

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN
DESSIN / DESIGN	GU	18 Aug. 2006	REV. 0
SIG / GIS	AC	28 Mar. 2007	
VÉRIFIÉ / CHECK	MR	12 Jul. 2006	
APPROUVÉ / REVIEW	MR	31 Jul. 2006	

FIGURE: C2.8-7

Project I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\mxd\Tenke_ESIA\Volume_C\FigureC2.8-8_Yr_Cumulative_PM10.mxd - Plot I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\pdf\Tenke_ESIA\Volume_C\FigureC2.8-8_Yr_Cumulative_PM10.pdf



LEGENDE / LEGEND

- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- EMPREINTE AU SOL / FOOTPRINT
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PRÉDICTIONS PM10 / PM10 PREDICTIONS

- 50 µg/m³
- 100 µg/m³

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY

2 0 2

ÉCHELLE 1:90000 KILOMÈTRES
SCALE 1:90000 KILOMETERS

RÉFÉRENCE / REFERENCE

Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

PRÉDICTIONS ANNUELLES CUMULATIFS SUR LE CAS DU PM_{10} /
ANNUAL CUMULATIVE PM_{10} PREDICTIONS

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	GU	18 Aug. 2006	FIGURE: C2.8-8	
SIG / GIS	AC	28 Mar. 2007		
VÉRIFIÉ / CHECK	MR	12 Jul. 2006		
APPROUVÉ / REVIEW	MR	31 Jul. 2006		

Volatile Organic Compounds (VOC)

If all mineral processing methods in the cumulative case will be the same type as proposed for the Kwatebala processing plant (which in not likely, due to ore differences) the ground level concentrations directly off site (2,600 micrograms per cubic meter) were within the Ontario ambient air quality criterion. The predicted ground level concentration, based on the Point of Impingement standard (for odour) from Ontario for mineral spirits, extends approximately 2.3 kilometers east to west (approximately 600 meters west of both plants).

The highest daily predicted ground level concentrations (10,204 micrograms per cubic meter) were well within the Shellsol 2325 occupational exposure limit of 350,000 micrograms per cubic meter.

Acid Mist (H_2SO_4/SO_3)

If all mineral processing methods in the cumulative case will be the same type as proposed for the Kwatebala processing plant (which in not likely, due to ore differences) the predicted ground level 1-hour acid mist concentrations (120 micrograms per cubic meter directly offsite) are within the OEHHA acute screening level of 120.

Impact Analysis

The expanded project is expected to have a negative impact for all contaminants considered (Table C2.8-13). It is unclear what the magnitude would be without the inclusion of additional information on the expansion including the type of ores that will be processed, the processing methods, and the location of future facilities. Refinement of the modeling conducted should be undertaken when more details on the expansion are known, and mitigation measures should be implemented if the consequences are still unacceptable.

Greenhouse gas emissions are predicted to have a moderate environmental consequence in terms of its contribution to the DRC due to the regional nature of the effect. However, use of hydropower for the processing plants will keep the magnitude of the effect low. The environmental consequence for all other parameters is predicted to be low.

Table C2.8-13 Residual Impact Classification for Cumulative Effects Case Key Question $AQ_{(ce)}$-1

Parameter	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question $AQ_{(ce)}$-1: What effect will emissions from operations of the cumulative project have on sensitive receptors?							
SO_2 24-hour	negative	low	local	medium-term	reversible	high	low
SO_2 annual	negative	low	local	medium-term	reversible	high	low
NO_2 24-hour	negative	low	local	medium-term	reversible	high	low
NO_2 annual	negative	low	local	medium-term	reversible	high	low
PM_{10} 24-hour	negative	low	local	medium-term	reversible	high	low
PM_{10} annual	negative	low	local	medium-term	reversible	high	low
CO 1-hour	negative	low	local	medium-term	reversible	high	low
GHG emissions	negative	low	regional	medium-term	reversible	high	moderate
VOC (naphtha 24-hour)	negative	low	local	medium-term	reversible	high	low
odor	negative	low	local	medium-term	reversible	high	low
acid mist	negative	low	local	medium-term	reversible	high	low

Prediction Confidence

In interpreting the GHG estimates it is important to note that it was assumed that the mining throughput would be a linear relationship to the production rate (i.e., as the copper production rate will increase from 115,000 tonnes per year to 400,000 tonnes per year. The assumption was made that the type of mineral processing proposed for Kwatebala will be implemented for the entire 400,000 tonne per year case. This is not likely. The predictions made, therefore, are made with a low prediction confidence.

In the prediction of SO_2 ground-level concentration impacts, the plant layout at Fungurume was assumed to be that of the Kwatabala with a doubling of emissions from the 115,000 tonnes of copper production scenario. The amount of acid required will be a function of the alkalinity and sulfide content of the future ores, as well as the mineral processing methods selected in the future. Therefore, the confidence of this prediction is low.

The cumulative PM_{10} emissions were assumed to incorporate wind erosion from all waste and topsoil storage piles as well as vehicle entrainment from the haul road activities.

Monitoring

Given the potential for high sulfur dioxide and inhalable particulate matter concentrations due to the proposed development, it would be beneficial to establish ambient monitors to measure these concentrations at the site and in the vicinity of human settlements.

The monitoring of gaseous and particulate emissions would assist in the establishment of a comprehensive emissions inventory to aid dispersion modeling exercises.

C2.8.5 Conclusions

Residual Impacts

The residual impact classification is given in Table C2.8-14. With mitigation, most effects are predicted to have a low environmental consequence. GHG emissions are expected to have a moderate environmental consequence due to the regional nature of the effect. However, these emissions represent a very small contribution to global carbon dioxide emissions.

Sustainability

Sustainability actions that could provide a long-term benefit to local communities include:

- Improvements to the local electrical grid and establishment of a local power distributor.
- Improvements to roads.
- Promotion of simple, fuel efficient stoves for household use would lead to an improvement in indoor air quality.
- Promotion of agroforestry and harvesting of non-timber forest products would lead to less deforestation as well as some tree planting and would aid in carbon sequestration.

These actions, once vetted by the communities, could have moderate sustainability consequences.

Table C2.8-14 Summary of Residual Impact Classifications for Air Quality Key Questions AQ-1 Through AQ-3

Parameter	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question AQ-1: What effect will construction emissions have on air quality in the receiving airshed?							
fugitive dust	negative	low[(a)]	local[(b)]	short-term	reversible	medium	low
combustion emissions	negative	low[(a)]	local[(b)]	short-term	reversible	medium	low
Key question AQ-2: What effect will emissions from operation of the proposed project have on sensitive receptors?							
SO_2 24-hour	negative	low	local	medium-term	reversible	high	low
SO_2 annual	negative	low	local	medium-term	reversible	high	low
NO_2 24-hour	negative	low	local	medium-term	reversible	high	low
NO_2 annual	negative	low	local	medium-term	reversible	high	low
PM_{10} 24-hour	negative	low	local	medium-term	reversible	high	low
PM_{10} annual	negative	low	local	medium-term	reversible	high	low
CO 1-hour	negative	low	local	medium-term	reversible	high	low
GHG emissions	negative	low	regional	medium-term	reversible	high	moderate
VOC (naphtha – 24-hour)	negative	low	local	medium-term	reversible	high	low
odor	negative	low	local	short-term	reversible	high	low
acid mist	negative	low	local	short-term	reversible	high	low
Key question AQ–3: What effect will closure have on air quality in the receiving airshed?							
fugitive dust	negative	low[(a)]	local[(b)]	short-term	reversible	medium	low
combustion emissions	negative	low[(a)]	local[(b)]	short-term	reversible	medium	low

(a) Magnitude based on professional judgment and the assumption that construction and closure effects will be lower than operational ones.

(b) Geographic extent based on professional judgement and the assumption that construction and closure effects will be lower than operational ones.

Cumulative Effects

It is predicted that daily sulfur dioxide and inhalable particulate matter are predicted to have moderate environmental consequence. However, due to various uncertainties associated with the proposed project expansion case, it is recommended that refinement of the modeling should be undertaken when more details on the expansion are known, and mitigation measures should be implemented if the consequences are still shown to be unacceptable. Greenhouse gas emissions are predicted to have a moderate environmental consequence due to the regional nature of the effect. However, use of hydropower for the processing plants will keep the magnitude of the effect low. The environmental consequence for all other parameters is predicted to be low.

C2.9 NOISE AND VIBRATION

C2.9.1 Introduction

This section presents the environmental assessment for the effects of the Tenke Fungurume Mining (TFM) project on noise and vibration. The information presented meets the project's terms of reference (Section E8) and includes details on:

- Noise concerns identified by stakeholders and regulators.
- Project activities that may affect noise and vibration.
- Mitigation measures incorporated in the project design for these impacts.
- The noise model and vibration analysis methods used for the assessment.
- Impact assessment approach and results for key issues including the comparison of predictions to criteria.
- Monitoring recommendations and identified mitigation measures to reduce residual noise impacts associated with the project.

The focus of the noise assessment is to determine changes to the existing ambient (surrounding) noise levels due to project operations. Noise guidelines from the World Bank Group (WBG) were the primary criteria assumed to be applicable for the assessment. Guidance from the World Health Organization (WHO) and the Democratic Republic of the Congo (DRC) New Mining Code (NMC) was considered as a guide to residential impact (Section A2.7). The United States Environmental Protection Agency (US EPA) guidelines were also used for outdoor residential areas (Section A2.7). The assessment is conducted from the point of view of human response. The effects of noise on wildlife are assessed in Section C3.2. Noise is also an input to the analysis of social effects in Section C4.1.

The impact of vibration is associated with blasting. While there are no applicable standards or criteria in place for vibration, predictions of vibration levels at dwellings are assessed. Guidelines for the TFM project were developed based on US (Federal Office of Surface Mining Reclamations and Enforcement [OSMRE]) vibration criteria (Section A2.7). Information from the DRC NMC is also referenced.

This section in the environmental and social impact assessment (ESIA) is organized as follows:

- Section C2.9.2 describes the study areas.
- Section C2.9.3 discusses the impact assessment approach and results.
- Section C2.9.4 provides the cumulative effects assessment.
- Section C2.9.5 discusses the conclusions of the assessment.

Baseline information concerning noise and vibration has been provided in Section B2.9.

A glossary of terms and acronyms used in this section is provided at the back of this volume.

C2.9.2 Study Areas

Two study areas were established to assess noise and vibration for the TFM project: a Local Study Area (LSA) and a Regional Study Area (RSA).

The RSA encompasses a region 30 by 17 kilometers that includes the mine, processing plant, road and limestone quarry activity (Figure C1.2-1). This area acts as the modeling domain for the assessment and is the study area for the cumulative effects assessment. Noise levels were determined over the RSA for use by the wildlife and social components. Vibration is only assessed within the LSA as it is a localized effect.

The LSA was used to identify specific sensitive receptors for the assessment. Any named villages in the region that were identified within two kilometers of the proposed Kwatebala mine, facilities, limestone quarry and within distances of 500 meters from roadways were considered sensitive receptors. Noise from the Goma and Fwaulu mines is assessed in the cumulative effects component only. These distances were assumed to include all the noise and vibration sensitive receptors potentially affected by the project activity. The villages identified as sensitive receptors for the noise assessment are (Figure C1.2-1):

- Tenke.
- Fungurume.
- Kafwaya.
- Kwatebala Gare.
- Mulumbu Kiasa.

- Mwela Mpande Gare.
- Bloc Mitumba.
- Salabwe.
- Mwanga Saugu.
- Mwanga Muteba (Shungu).

These villages were determined to be the primary residential areas within the LSA, based on the results of the socio-economic surveys (Section B4.1). It is important to note that the villages of Mulumbu, Amoni and Kiboko are not identified as receptors since relocation of these settlements is planned (Section D4.4). Potential locations for resettlement villages will be selected taking noise impacts into account.

The vibration assessment focused on the presence of structures. The nearest structures to blasting activity were dwellings used seasonally by farmers 650 meters south of the pit. This was assessed as a worst case.

C2.9.3 Impact Assessment

C2.9.3.1 Issue Scoping

Through consultation with stakeholders and review of previous environmental assessments for resource developments several issues were identified with respect to the potential impacts of noise and vibration from the project.

Project factors that may affect noise levels include:

- The mine ore excavation and haulage fleet.
- The surface miner in the mine pit.
- The waste rock excavation and haulage fleet.
- The processing plant equipment including boilers, pumps, fans, mills, compressors and miscellaneous motors.
- Mobile equipment on site access roads, including increased activity during the construction phase.
- Equipment in the limestone quarry.
- Material transport trucks and worker vehicles resulting in increased traffic on public roadways.

Blasting is the only project activity that may substantially affect vibrations. Vibration may also be caused by haul truck and access road traffic.

C2.9.3.2 Key Questions and Indicators

The key questions for noise and vibration are listed in Table C2.9-1.

Table C2.9-1 Key Questions for Noise and Vibration

Impact Assessment
N-1: What effect will the project have on noise levels near project activities?
V-1: What effect will the project have on vibration?

Examination of sustainability issues in the assessment was not considered appropriate as noise is not linked to a potential commodity or economic element.

The indicators used for the ESIA are provided in Table C2.9-2. Theses include noise, ground vibration and airborne vibration at residences (receptors) closest to the project.

Table C2.9-2 Indicators for Noise and Vibration

Component	ESIA Indicator	Units	Description
noise	L_{eq} (equivalent level of energy) at nearest residences	dBA	an environmental noise measure that presents natural noise variability over time as a single unit based on human response
vibration	Ground vibration at nearest residences	mm/s	the maximum velocity the ground moves during a vibration caused by a ground borne pressure wave
	airborne vibration at nearest residences	dBL	Instantaneous pressure wave due to noise event

dBA = A-weighted decibels.
mm/s = Millimeters per second.
dBL = Linear decibels.

The key indicator which will be used to assess potential changes in noise levels is the equivalent sound level or L_{eq}. This indicator is a logarithmic average that represents noise levels measured over a selected period of time. L_{eq} is measured in A-weighted decibels to mirror the response of the human ear. This type of average is commonly used in an environmental (outdoor) context as it takes into account natural variations in sound.

The key indicators for vibration are:

- **Ground vibration** - the amount of ground displacement per pressure wave, measured in millimeters per second.

- **Airborne vibration** - the instantaneous pressure wave measured in linear decibels (dBL).

C2.9.3.3 Assessment Criteria

Noise

Noise guidelines established for the project (Section A2.7) represent the noise levels that the project must meet to avoid impacts.

Table C2.9-3 lists the applicable noise guidelines that will be used to rate impacts for the project. The values presented are equivalent level of energy Leq in weighted decibels over the time periods indicated and are applied at receptors (residences or communities) outside the project boundary.

Table C2.9-3 Noise Guidelines for the TFM Project

Type of Land Use	L_{eq} Limits[(a)]	
	Night (dBA)	Day (dBA)
residential[(b)]	45	55
industrial	70	70

(a) (WBG 1998). Pollution, Prevention and Abatement Handbook (PPAH). General Environmental Guidelines. Night is defined as 22:00 to 07:00. Day is defined as the remaining hours, 07:00 to 22:00.

(b) If ambient noise is greater than the criteria, a maximum increase of three A weighted decibels over ambient is allowed.

L_{eq} = equivalent sound level.

dBA = A-weighted decibels.

Under the DRC 2002 Mining Law, the maximum noise level of mining or quarry activities must be below the highest of the following noise levels:

- The maximum authorized noise level depending on the category of land. The night-time noise limit for land category (a) is 40 A-weighted decibels. Category (a) is land comprising several dwellings of a residential nature constituting a village, a school or a hospital or any other establishment procuring educational, health or convalescence services.
- The noise level matching the measured ambient noise level when the mining activities of the project have been completely stopped.

In the cases where the measured ambient noise level is below 40 A-weighted decibels, the DRC NMC has a more strict night-time limit of 40 A-weighted decibels for non-industrial rural areas (Section A2.7) This standard will be used as a basis for comparing impacts but will not be used for rating impacts.

Residual impacts are determined at sensitive receptors based on the WBG criteria. According to the Pollution Prevention Handbook 1998, the noise sensitive receptors are people located in any residential, industrial and educational land use outside the project property boundary. For the purpose of this assessment, any named villages in the region that were identified within two kilometers of the proposed mine, facilities, limestone quarry and within distances of 500 meters from roadways were considered sensitive receptors. The parameters used to determine environmental consequence at the community receptors are direction, magnitude, geographic extent, duration, reversibility and frequency, as presented in Table C2.9-4.

Table C2.9-4 Impact Description Criteria for Noise

Direction[a]	Magnitude[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
neutral: no change in noise **negative:** an increase in noise **positive:** a reduction in noise	**negligible:** criteria met and no noticeable change to baseline **low:** criteria met but noticeable change to baseline **moderate:** some criteria not met or noticeable change to baseline **high:** all criteria not met or noticeable change to baseline	**local:** effect restricted to the LSA **regional:** effect extends beyond the LSA	**short-term:** less than 3 years **medium-term:** 3 to 20 years **long-term:** more than 20 years	**reversible** or **irreversible**	**low:** occurs once **medium:** occurs intermittently **high:** occurs continuously

[a] Direction: positive or negative effect for measurement indicators as defined for the specific component.
[b] Magnitude: degree of change to analysis indicator.
[c] Geographic Extent: area affected by the impact.
[d] Duration: length of time over which the environmental effects occurs. Considers a two-year construction period and a 20-year operation period.
[e] Reversibility: effect on the resource (or resource capability) can or cannot be reversed.
[f] Frequency: how often the impact occurs.

The impact magnitude ratings for noise are derived from the WBG guidelines:

- **Negligible** - Predicted noise levels are below the WBG criteria and will not affect baseline noise levels by more than three A-weighted decibels.
- **Low -** Predicted noise levels are below the WBG criteria but will increase period (day or night) baseline noise levels by more than three A-weighted decibels, where baseline levels are below WBG criteria.
- **Moderate -** Predicted noise levels are above the WBG night-time criteria but below the daytime criteria. Where baseline levels are above WBG criteria, noise levels increase by more than three A- weighted decibels.

- **High -** Predicted noise levels exceed both the WBG daytime and night-time criteria. Where baseline levels are above WBG criteria, noise levels increase by more than three A-weighted decibels.

An incremental change of plus or minus three A-weighted decibels is used to evaluate change. A change of three A-weighted decibels is considered the threshold level at which a change in sound level or "volume" can be noticed by the human ear (Cowan 1994).

Figure C2.9-1 shows the noise impact magnitude decision process.

Vibration

Ground Vibration

Ground vibration is typically measured in terms of particle velocity in millimeters per second. Criteria are established to prevent cosmetic and structural damage to structures that may occur from ongoing vibration sources and from blasting

Criteria for project assessment have been developed based on vibration criteria for the US Office of Surface Mining Reclamation and Enforcement (OSMRE) (Table C2.9-5). There are no applicable standards or limits in place for vibration exposures in the DRC. Blasting regulations exist in most countries to regulate and control blast energy to prevent structural damage at neighboring properties. In the absence of World Bank and IFC limits for vibration, the US, Canadian and DRC limits were used as guidelines in ground and air vibration. These regulations address both ground and airborne vibration.

Table C2.9-5 Groundborne Vibration Guidelines for the TFM Project

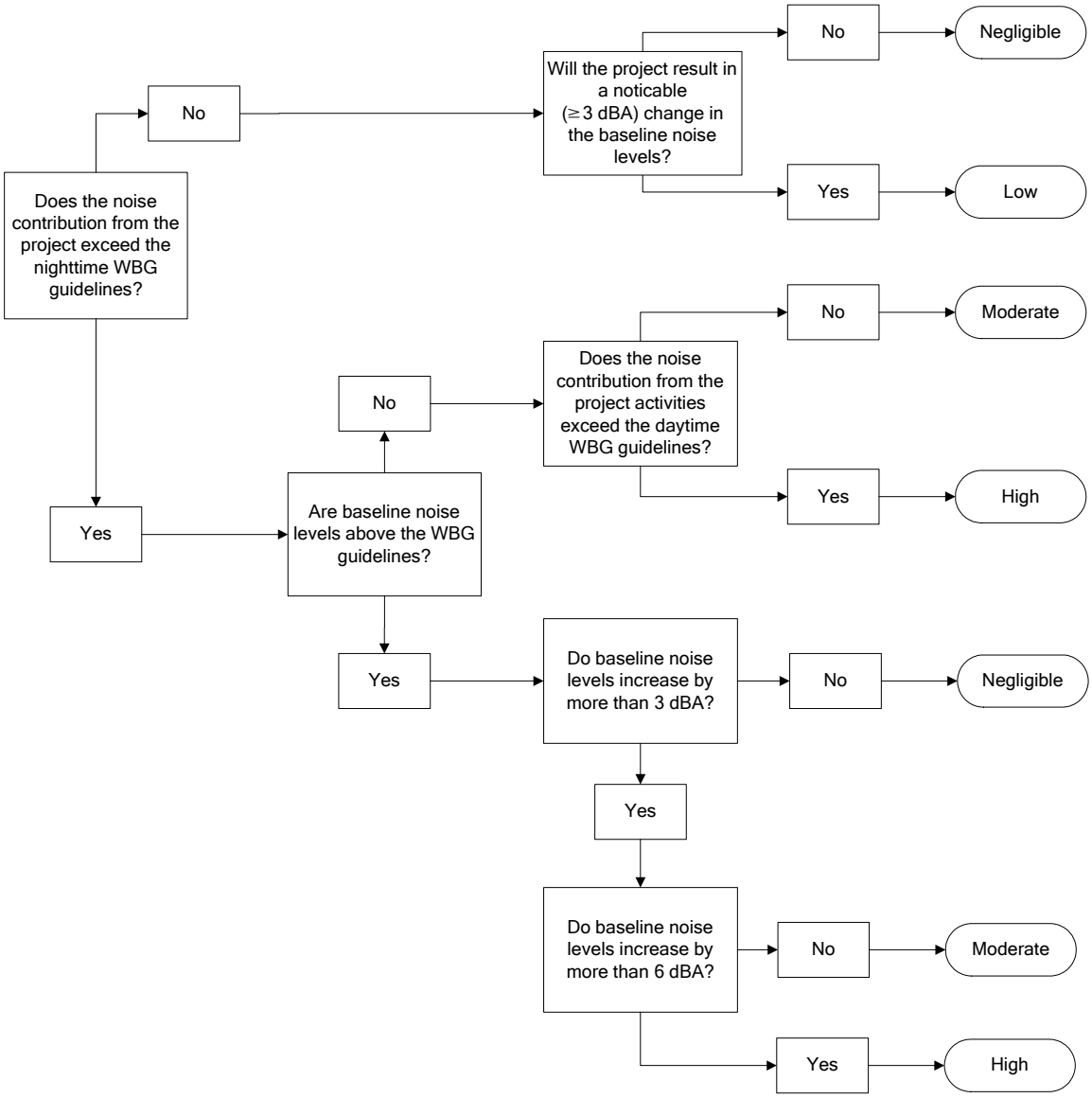
Type of Building	US [(a)]
	Structural (mm/s)
residential (light frame)	12.5
industrial (concrete or steel frame)	12.5

[(a)] Federal Office of Surface Mining Reclamation and Enforcement (OSMRE 2001).

mm/s = millimeters per second.

The US limit for groundborne vibration is listed at 12.5 millimeters per second to prevent structural damage or disturbance in residential and industrial areas. This is the recommended criterion for vibration from the project. This criterion is equivalent to Annex IX of the DRC 2003 Mine Regulation.

Figure C2.9-1 Noise Impact Magnitude Decision Tree



Airborne Vibration

Blasting regulations exist in most countries to regulate and control blast energy to prevent structural damage at neighboring properties. Airborne vibration limits commonly used for surface mining operations where blasting can be expected to occur over many years, typically fall in the range of 120 to 133 linear decibels. Table C2.9-6 indicates guidelines that can be used to assess impact from this source. These airborne events are the blast wave that propagates through the atmosphere out from the blast and can be experienced as a brief but intense incident of low frequency noise or vibration.

Table C2.9-6 Airborne Vibration Guidelines for the TFM Project

	DRC[(a)]	United States[(b)]	Canada[(c)]
airborne vibration limit	120 dBL	129 – 134 dBL[(d)]	120 - 128 dBL[(e)]

(a) Section 48 of DRC Mine Regulation 2003 Annex IX.

(b) Office of Surface Mining Reclamation and Enforcement.

(c) Ontario Ministry of Environment Publication NPC 119.

(d) Limit dependent on frequency range of instrumentation.

(e) Limit dependent on whether monitoring is carried out continually.

Similar to noise, residual impacts from groundborne and airborne vibration are determined at the point of reception. The parameters used to determine environmental consequence at the receptors (residences or communities) are direction, magnitude, geographic extent, duration, reversibility and frequency (Table C2.9-7). The only parameter that has a unique definition for vibration is magnitude. The magnitude ratings are derived from the above guidelines and are based on:

- **Negligible** - Predicted vibration levels are below the US guidelines.
- **Low** - No definition.
- **Moderate** - No definition.
- **High** - Predicted vibration levels exceed the guidelines.

There are no intermediary ratings for magnitude as the criteria are either met or not. There is no basis for a graduated effect.

C2.9.3.4 Key Question N-1

Key question N-1 is: What effect will the project have on noise levels near project activities?

Table C2.9-7 Impact Description Criteria for Vibration

Direction[a]	Magnitude[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
neutral: no change in vibration indicator **negative:** an increase in vibration levels **positive:** a reduction in vibration levels	**negligible:** predicted vibration levels below guidelines **high:** predicted vibration levels exceed guidelines	**local:** effect restricted to the LSA **regional:** effect extends beyond the LSA	**short-term:** less than 3 years **medium-term:** 3 to 20 years **long-term:** more than 20 years	**reversible** or **irreversible**	**low:** occurs once **medium:** occurs intermittently **high:** occurs continuously

[a] Direction: positive or negative effect for measurement indicators as defined for the specific component.

[b] Magnitude: degree of change to analysis indicator.

[c] Geographic Extent: area affected by the impact.

[d] Duration: length of time over which the environmental effects occurs. Considers a two-year construction period and a 20-year operation period.

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

[f] Frequency: how often the impact occurs.

Linkage Evaluation

Noise may be generated during all phases of the project, particularly during operation of the mine and processing plant (Figure C2.9-2). An initial review of noise-generating activity identified that the type of noise phases during all project stages were similar (engines, pumps, etc.). The construction phase activities are characterized by many transient noise sources but they are temporary. The number of noise sources was expected to be relatively low during project closure compared to project operation. A detailed assessment was only conducted for project operation.

Noise can affect both people (Section C4.1) and fauna (Section C3.2). The linkage to noise levels near project activities is considered valid.

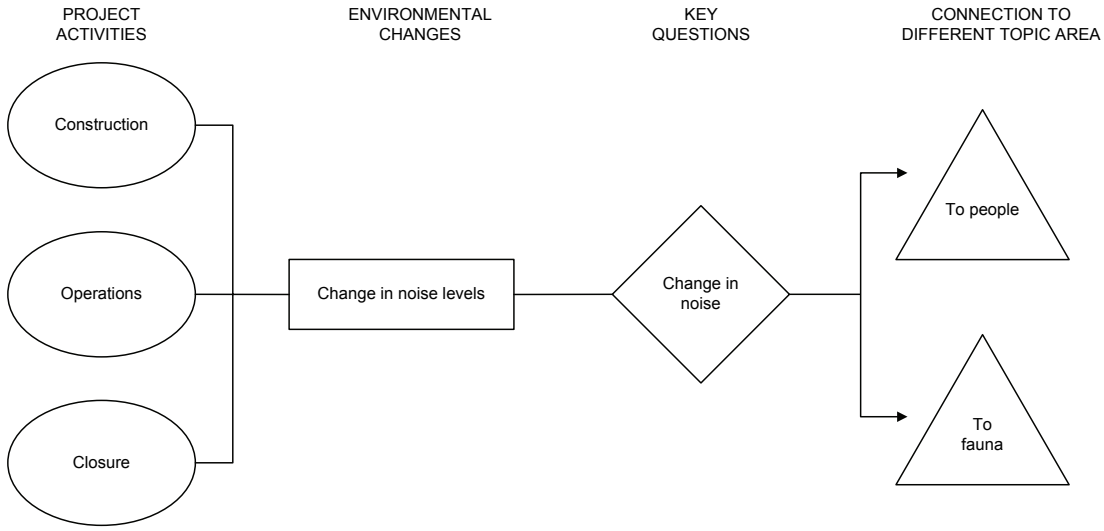
Assessment Methods

Approach

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 generated by project activity.
- Predicting the amount of project-related noise that would be experienced at the identified receptors.
- Comparing predicted noise levels with baseline noise levels and applicable noise guidelines.

Figure C2.9-2 Noise Linkage Diagram



Noise predictions were conducted using the Computer Aided Noise Abatement Model (CadnaA). This model was used to estimate noise levels received at neighboring 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. The CadnaA model includes effects from the atmosphere, barriers, ground conditions, foliage and terrain. The model methods are consistent with International Organization for Standardization (ISO) acoustic standards and WBG guidelines.

Noise Emissions

Activities or equipment that emit sound were identified based on information contained in the project description and client-supplied equipment lists where specifications were provided. Sound emissions for the sources without noise specifications were based on noise measurements from similar equipment, manufacturer data or standard sound emission formulas.

Sources of noise considered for the noise assessment are summarized by project activity in Table C2.9-8.

Table C2.9-8 Noise Emissions for the TFM Project

Source	Type of Source[a]	Sound Power (dBA)[b]
Plant Site		
area 20 grinding	point	107
area 30 leach feed	area	109
area 40 CCD[c]	area	110
area 50 neutralization and tails	area	104
area 60 solvent extraction	area	109
area 70 copper electrowinning	area	113
area 80 cobalt recovery	area	114
area 90 sulfuric acid plant	area	109
area 103 dolomite	point	102
area 104 lime	point	92
area 105 magnesia storage and mixing	area	106
area 106 sodium hydroxide and mixing	area	93
area 110 potable/gland water	point	109
area 111 air compressor	point	114
area 112 boiler house	area	83
conveyors	line	121
plant light vehicle	line	81
plant fork lift	line	116
plant delivery truck	line	100
plant mobile crane	line	111
Mine Site		
Kwatebala ore pit (included surface miner)	area	128 (year 2010 and 2016)
Kwatebala waste rock facility	area	122 (year 2010 and 2016)
Kwatebala stockpiles	area	124 (year 2010) 125 (year 2016)
waste pile fleet CAT773F	line	115[d]
ore fleet CAT770	line	113[d]
stockpile fleet CAT773F	line	115[d]
Quarry		
Mofia quarry	area	117 (year 2010 and 2016)
Public Roads		
highway trucks	line	107
highway light vehicle	line	81.3

[a] The type of source indicates how the emission was represented in the model. Area sources spread the emission over the relevant site for the activity, line sources move the sources along a given trace (e.g., roads) and point sources are a designated stationary location.

[b] dBA = A-weighted decibels

[c] CCD = countercurrent Decantation

[d] Sound power level per equipment unit (e.g., each CAT773F)

Modeling Assumptions

All mine-related noise sources were modeled by an established and validated noise model, the CadnaA model. This model was designed to predict outdoor noise in accordance with International Organization for Standardization (ISO) 9613 (1 and 2): Attenuation of Sound During Propagation Outdoors (ISO 9613) as well as several international and European acoustic standards. The function of the model is to reproduce the planned site conditions. All noise sources operating at their predicted noise levels are subject to the likely outdoor conditions prevailing at the site. The CadnaA model helps to assess the noise source's attenuation in their path to the receptor. These prevailing outdoor conditions include terrain, weather and ground conditions. The noise model used presents a snapshot of the expected continuous noise levels generated from the processing plant. To ensure a "worst case" assessment for the processing plant, a highest expected noise level was assessed. The model was based on the assumption that all equipment will be in use at the design capacity. The location and number of mobile equipment were also included in the model to represent a worst case scenario in terms of the noise heard by the receptor during the Kwatebala mine phase.

Over the projected mine life of 20 years the location and numbers of equipment will change according to the stage of ore recovery from the Kwatebala, Goma, and Fwaulu deposits. Noise predictions were based on these changes being staged at the second (2010) and eighth (2016) years into the project. These were the periods with the highest potential noise effects during the Kwatebala mining phase. Year 2010 was selected to represent the highest total mined ore and waste tonnage at an elevation close to the surface (i.e., without attenuation from the pit walls). Year 2014 was selected as a later mining year at Kwatebala Hill when there will be high production and there will be waste rock facility activities closest to the sensitive receptors.

The noise effects during the Goma and Fwaulu mining phases is assessed in the cumulative effects section. The Monitoring and Follow Up section discuss the monitoring plan required to substantiate the emission levels from the mine fleet and pit.

The mine plan at years 2010 and 2016 provides information as to what noise sources will be operating and their locations (Section A4). The model assumptions for both stages are as follows:

- All calculations were conducted based on the ISO 9613 standard (including roads).
- Meteorological conditions were set at a temperature of 25 degrees Celsius and relative humidity 90 percent as a typical condition.

- All activity, including road traffic, would occur for 24 hours.
- All traffic would access the site using the Mulumbu access road in year 2010.
- Only sources within 10 kilometers of a receptor were considered.

Mitigation

The following mitigation, controls or project elements will reduce noise impacts:

- A surface miner will be used to mine at the Kwatebala, Goma and Fwaulu pits. This will eliminate the need to drill, blast and primary crush the ore.
- Construction fleet or equipment will be fitted with standard silencers and kept in good repair.
- The ore, waste rock facilities, structures and buildings will act as barriers to noise generated by the mine and processing plant.
- Waste rock will be used strategically to create barriers, based on indicated need in the form of results from noise monitoring.
- All operation vehicles (mine fleet and off-site transport) will be fitted with standard silencers (mufflers) and kept in good repair.

Use of the continuous miner (Section A4.3.1) for mining ore in the mine pit will reduce the need for blasting. It will also eliminate the need for a crusher. The noise created by the continuous miner will occur in the mine pit where the pit walls will provide additional attenuation.

Results

The results of noise predictions for activity related to the Kwatebala pit and processing plant show the expected noise levels at the receptor locations situated at each village for years 2010 and 2016 (Table C2.9-9). The results range from 16 to 39 A-weighted decibels (day and night) in year 2010 and from 10 to 40 A- weighted decibels in year 2016. Daytime and night-time values are identical due to the assumption that all project activities operate on a 24-hour basis. This may result in a more conservative case at night, when there would likely be less traffic on public roads.

Table C2.9-9 Predicted Noise Levels from TFM Project Activities

Location	Year 2010 (Day and Night) L_{eq} (dBA)	Year 2016 (Day and Night) L_{eq} (dBA)
Kafwaya	16	10
Mwela Mpande Gare	19	19
Kwatebala Gare	29	27
Bloc Mitumba	22	22
Fungurume	36	36
Mulumbu Kiasa	34	35
Mwanga Saugu	37	38
Salabwe	39	40
Mwanga Muteba (Shungu)	37	36
Tenke	24	23

(a) Leq = equivalent sound level.
(b) dBA = A-weighted decibels.

Predicted noise levels are also presented as noise maps in Figure C2.9-3 and Figure C2.9-4.

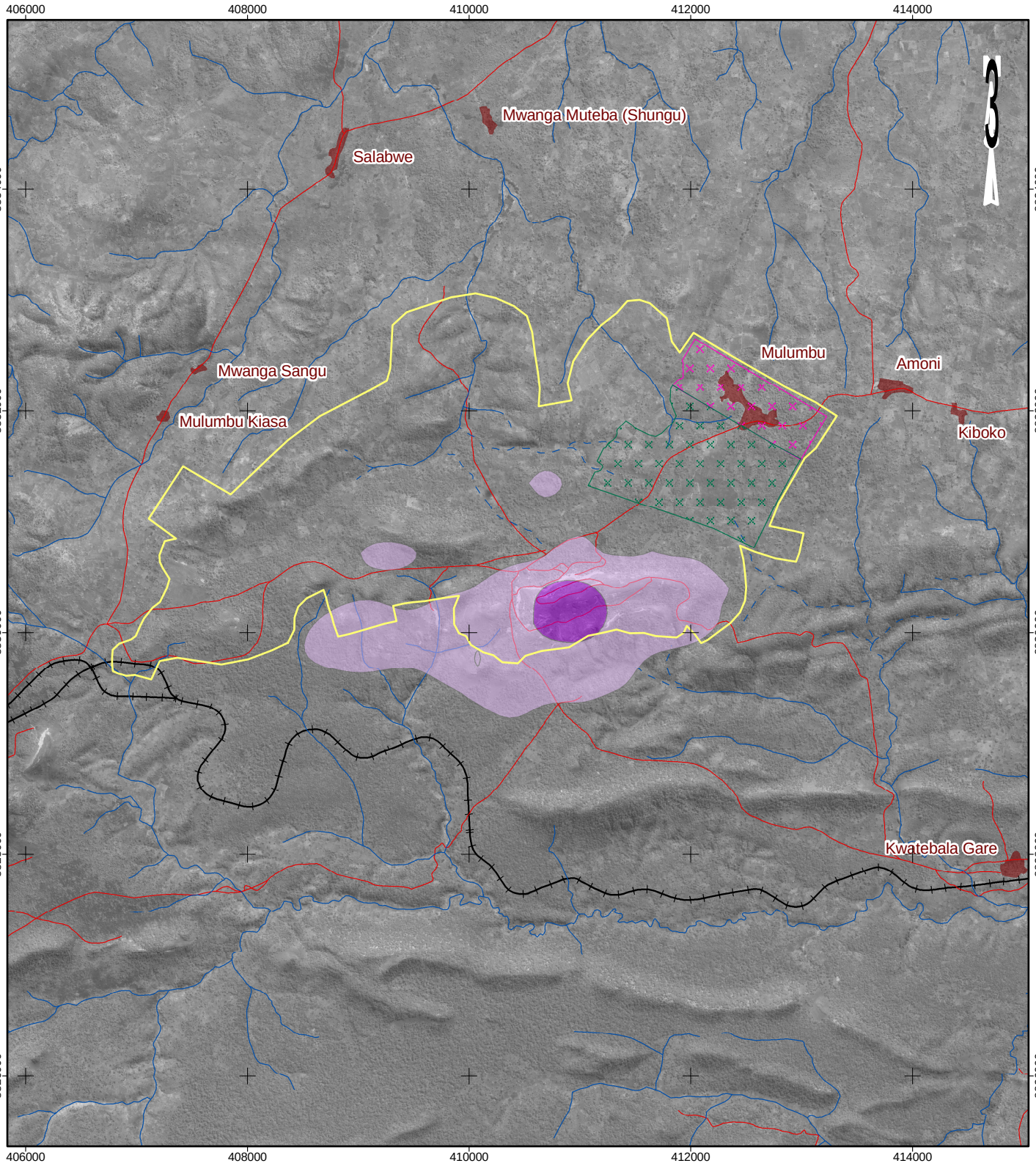
The noise predictions at potential locations for resettlement villages are levels below 35 A-weighted decibels during the daytime and night-time period.

Impact Analysis

The analysis for noise impacts has three elements:

- A comparison of predicted noise levels to WBG guidelines applied to the project.
- A comparison of predicted noise levels to the DRC NMC.
- A determination of the amount of change in baseline noise levels. Table C2.9-10 compares the predicted noise levels to the WBG guideline. Table C2.9-11 provides an analysis of the amount of change in baseline noise levels.

The results of these comparisons show that the WBG and DRC guidelines are met for all locations assessed.



LÉGENDE / LEGEND

- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- EMPREINTE AU SOL / FOOTPRINT
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PRÉDICTIONS PM_{10} / PM_{10} PREDICTIONS

- 150 µg/m³
- 500 µg/m³

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY

RÉFÉRENCE / REFERENCE

Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

PRÉDICTIONS JOURNALIÈRES DU SCÉNARIO
PROJET RÉALISÉ SUR LE CAS DU PM_{10} /
HIGHEST DAILY PROJECT PM_{10} PREDICTIONS

Golder Associates
Calgary, Alberta

N° projet / project no. 05-1334-035			Échelle telle qu'indiquée / Scale as Shown	REV. 0
DESSIN / DESIGN	GU	22 Jun. 2006		
SIG / GIS	AC	28 Mar. 2007		
VÉRIFIÉ / CHECK	MR	12 Jul. 2006		
APPROUVÉ / REVIEW	MR	31 Jul. 2006		

FIGURE: C2.8-3

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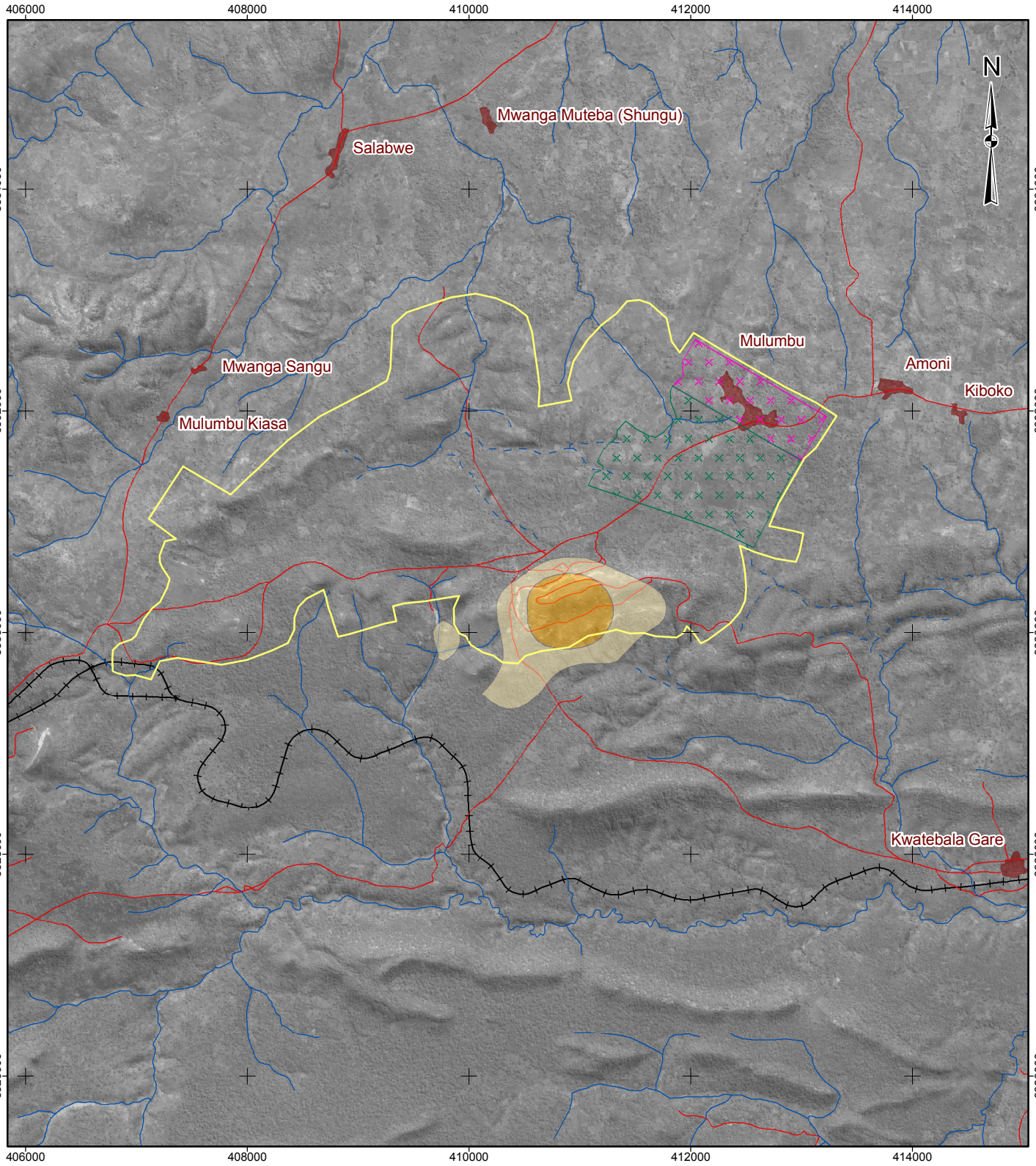

ÉCHELLE / SCALE 1:50000 KILOMÈTRES / KILOMETERS

LÉGENDE / LEGEND

- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- EMPREINTE AU SOL / FOOTPRINT
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PRÉDICTIONS PM_{10} / PM_{10} PREDICTIONS

- 50 µg/m³
- 100 µg/m³

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY

RÉFÉRENCE / REFERENCE

Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

PRÉDICTIONS ANNUELLES DU SCÉNARIO PROJET RÉALISÉ SUR LE CAS DU PM_{10} / HIGHEST ANNUAL PROJECT PM_{10} PREDICTIONS

Golder Associates
Calgary, Alberta

N° projet / project no. 05-1334-035			Échelle telle qu'indiquée / Scale as Shown	REV. 0
DESSIN / DESIGN	GU	22 Jun. 2006		
SIG / GIS	CW	16 Feb. 2007		
VÉRIFIÉ / CHECK	MR	12 Jul. 2006		
APPROUVÉ / REVIEW	MR	31 Jul. 2006		

FIGURE: C2.8-4

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Table C2.9-10 Comparison of Predicted Noise Levels with World Bank Group Guidelines

Location	Highest Predicted Sound Level (Day and Night) (dBA)	WBG Guideline (dBA)		Meets WBG Guideline (Yes/No)	DRC Residential Guideline (dBA)		Meets DRC Guideline (Yes/No)
		Day 7:00 hr to 22:00 hr	Night 22:00 hr to 7:00 hr		Day 7:00hr to 19:00hr	Night 19:00hr to 7:00hr	
Kafwaya	16	55	45	yes	45	40	yes
Mwela Mpande Gare	19	55	45	yes	45	40	yes
Kwatebala Gare	29	55	45	yes	45	40	yes
Bloc Mitumba	22	55	45	yes	45	40	yes
Fungurume	36	55	45	yes	45	40	yes
Mulumbu Kiasa	35	55	45	yes	45	40	yes
Mwanga Bijimba	38	55	45	yes	45	40	yes
Salabwe	40	55	45	yes	45	40	yes
Mwanga Muteba (Shungu)	37	55	45	yes	45	40	yes
Tenke	24	55	45	yes	45	40	yes

Table C2.9-11 Expected Change in Baseline Noise Levels

Location	Period	Baseline L_{eq} (dBA) [(a)]	Predicted Project Noise Level (dBA)	Combined Noise Level (dBA)	Amount of Change (dBA)
Kafwaya	day	44	16	44	0
	night	44	16	44	0
Mwela Mpande Gare	day	44	19	44	0
	night	44	19	44	0
Kwatebala Gare	day	50	28	50	0
	night	47	28	47	0
Bloc Mitumba	day	44	22	44	0
	night	44	22	44	0
Fungurume	day	42	36	43	1
	night	43	36	44	1
Mulumbu Kiasa	day	44	24	44	1
	night	44	34	44	1
Mwanga Saugu	day	44	38	44	1
	night	44	38	44	1
Salabwe	day	44	40	45	1
	night	44	40	45	1
Mwanga Muteba (Shungu)	day	44	36	44	1
	night	44	36	44	1
Tenke	day	49	24	49	0
	night	39	24	39	0

(a) Baseline levels established (Section B2.9).

dBA = A-weighted decibels.

The assessment predicts that the highest noise level caused by project activities at all noise sensitive receptors is 40 A-weighted decibels. This value was obtained for the night-time period at the rural village of Salabwe. Notably, the current background noise level at Salabwe is 44 A-weighted decibels. Therefore, the standard applicable to the project at Salabwe is conservatively 44 A-weighted decibels. This is conservative as the future background noise level at Salabwe could very well be higher due to in-migration of people and development that will likely occur over the life of the project. We expect that the measured ambient noise level, when mining activities cease, will be at or above the current background level of 44 A-weighted decibels.

The predicted noise level from project-related noise at Salabwe is 40 A-weighted decibels. This is below the maximum authorized noise level of 44 A-weighted decibels. The project therefore will meet the DRC 2002 Mining Law standard.

It is worthy to note that there is no existing industrial activity in this small village located on the project concession. The basis for the assessment undertaken in the ESIA are the existing conditions in the affected areas and not the resulting land use after the project is in place. In other words, the noise assessment is purposely conservative based on an assumption that all small villages are within land category (a). The predicted noise level at potential locations for resettlement villages are below both WBG and DRC NMC guidelines. Baseline noise levels will also be unchanged at all locations except Fungurume, Mulumbu Kiasa, Mwanga Saugu, Salabwe, and Mwanga Muteba (Shungu). These changes are only expected to be about one A-weighted decibel. This will result in impact magnitude ratings of negligible at all identified receptors for the project. The residual effect for noise impacts is analyzed in Table C2.9-12.

Table C2.9-12 Residual Impact Classification for Key Question N-1

Location	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
N-1: What effect will the project have on noise levels near project activities?							
Kafwaya	negative	negligible	local	medium-term	reversible	high	negligible
Mwela Mpande Gare	negative	negligible	local	medium-term	reversible	high	negligible
Kwatebala Gare	negative	negligible	local	medium-term	reversible	high	negligible
Bloc Mitumba	negative	negligible	local	medium-term	reversible	high	negligible
Fungurume	negative	negligible	local	medium-term	reversible	high	negligible
Mulumbu Kiasa	negative	negligible	local	medium-term	reversible	high	negligible
Mwanga Saugu	negative	negligible	local	medium-term	reversible	high	negligible
Salabwe	negative	negligible	local	medium-term	reversible	high	negligible
Mwanga Muteba (Shungu)	negative	negligible	local	medium-term	reversible	high	negligible
Tenke	negative	negligible	local	medium-term	reversible	high	negligible

As shown in Table C2.9-12, residual noise impacts from the TFM project are expected to be negligible at the identified sensitive receivers (receptors). The predicted noise levels presented in Table C2.9-9 also all meet the most strict noise standard from the DRC (40 A-weighted decibels at night).

The negligible impact rating does not mean that project noise won't be heard at these locations. This is because the character or type of noises being generated by the TFM project are different than those that occur in the region. This is particularly true for the outlying villages away from the main roadway. The results mean that if project noises are distinguishable (noticeable) from ambient noise, the project noises are not expected to be any louder than existing noises.

Prediction Confidence

The modeling of outdoor noise attenuation is conducted using standard algorithms (mathematical formulas) and assumptions that tend to simplify the acoustic environment. Noise, whether natural or man-made, is normally variable over time. The algorithms and the equivalent sound level 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 depends on the data inputs. For the assessment, noise sources were established with actual field measurements or vendor sound emission data where possible to ensure the accuracy of sources. Site topographic, weather and ground conditions were inputs to the model. Modeled noise levels for the existing activity on the project 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 Organization for Standardization (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 plus or minus three weighted decibels. 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 (Drew et al 2005). This study verified that the CadnaA model calculates the ISO method correctly. This study also verified that simulations of outdoor noise levels match field measurements of a known source to within plus or minus three weighted decibels.

Monitoring and Follow Up

All impacts are rated negligible for the Kwatebala mine phase. However, a one time noise monitoring program should be established to measure the noise sources from the processing plant, mine fleet and mine pit equipment. The program will provide site-specific data for future assessments of the Goma and Fwaulu pit phases. Additionally, noise sources may be measured at the project site to quantify workplace levels.

Should noise concerns be expressed by the public during the Kwatebala mine phase, monitoring could be conducted to determine the noise source that is the cause for concern.

C2.9.3.5 Key Question V-1

Key question V-1 is: What effect will the project have on vibration?

Linkage Analysis

The project factors that may affect vibration are heavy vehicle traffic on public roadways and blasting during operations. High levels of vibration can cause structural damage to buildings while at lower levels can still cause annoyance to people.

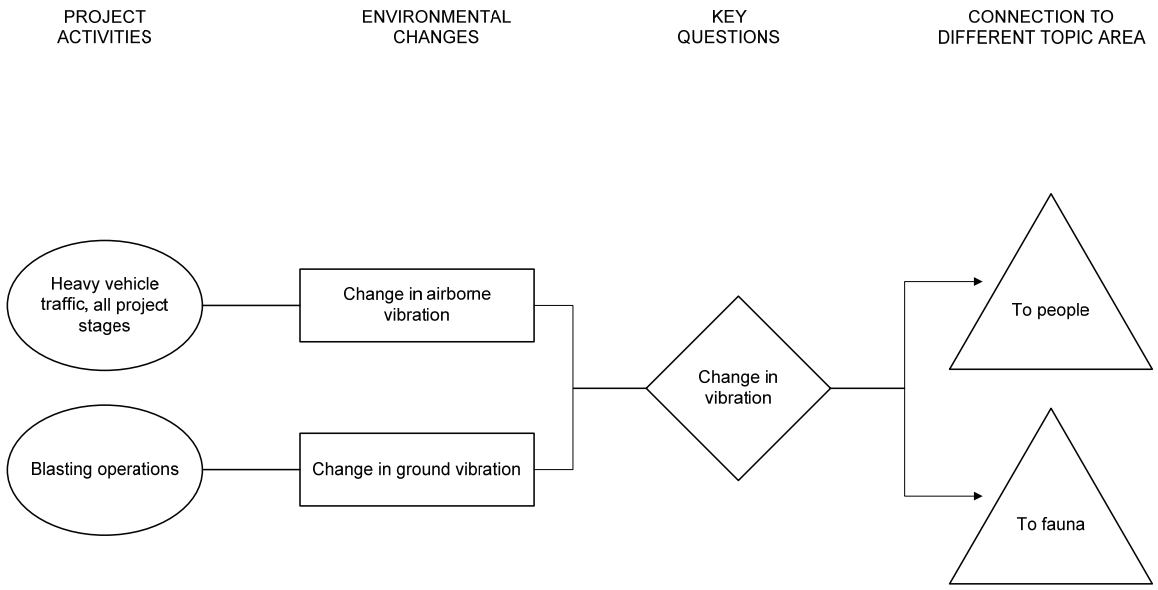
An analysis of factors that may affect vibration is shown as a linkage diagram in Figure C2.9-5.

Effect on Structures

Traffic, particularly heavy vehicles, can generate airborne and groundborne vibrations, often felt by people in homes near roadways. This most often occurs in homes with rigid (concrete) foundations when large, heavy vehicles traveling at high speeds encounter imperfections/pot holes in concrete or asphalted roadways. Vibrations can also be felt when people are near “off road” heavy vehicles on the project site. Since roads are not paved in the majority of the LSA, homes do not have rigid (concrete) foundations and “off road” vehicles will only be on site, the linkage between traffic and damages to off-site structures is not valid.

Vibrations from blasting may affect structures, if the structure is close enough and the vibration intensity is high enough. The linkage to blasting on structures is valid.

Figure C2.9-5 Vibration Linkage Diagram



Effect on Water Wells

Several studies have investigated the effects of blasting on groundwater wells (Froedge 1983). These studies have concluded that:

- When blast-induced ground vibrations are less than about 25 millimeters per second (maximum resultant particle velocity), the response of the well is limited to a slight temporary variation in water level. This variation is about three to six centimeters either up or down. The specific capacity of the water well is unchanged based on drawdown tests.
- Vibration measurements made at the surface and at the bottom of the observation wells indicate that vibration levels are always lower at the bottom of the well.
- All of the data collected indicates that a ground vibration limit of 50 millimeters per second (peak particle velocity) is adequate to protect the wells from any significant damage. It is possible that temporary turbidity (disturbed sediments) may be caused at lower well levels periodically, although not at any constant threshold level.

The research consistently indicates that blast vibrations less than 25 millimeters per second should have no adverse effects on nearby wells. This level is higher than the 12.5 millimeters per second groundborne vibration US limit used for the TFM operation project. The linkage to blasting on water wells is invalid.

Assessment Methods

Blasting activities are identified as the source for both groundborne and airborne vibration. US criteria for groundborne vibration, and DRC, Canadian and US based criteria for airborne vibration were the sets of criteria used as the most applicable for the TFM project. The level of vibration experienced by receptors will be directly related to the amount of charge (explosive material) used for a blast.

Hypothetical blasting charge quantities were determined that would result in vibration levels at receptors equal to the criteria. These hypothetical blasting charge quantities were then compared with actual charge quantities planned for the mine blasting program. The comparison was conducted to determine whether actual blasting charges used would result in vibration levels below criteria levels. The results indicated that actual blasting charges used would result in vibration levels well below criteria levels. Typical blast design details for the TFM project are provided in Table 2.9-13. Note that blasting will only be required for removal of waste rock. A surface miner will be used to mine the ore.

Table C2.9-13 Typical Blast Design Details Proposed for the TFM Project

Material	Parameter	Dimension
waste rock	drill hole pattern	3.5 x 4.4 m
	drill hole diameter	102 mm
	maximum holes per blast [(a)]	150
	maximum explosive weight per hole	30 - 45 kg
	hole depth	5.8 m
	maximum holes per delay	1

[(a)] Based on assumed explosive densities of 0.9 g/cc for ANFO and 1.1 g/cc for emulsion.

Notes:
m = meters.
mm = millimeters.
kg = kilograms.
g = grams.
cc= cubic centimeters.
ANFO= ammonium nitrate fuel oil.

The residual impact analysis was then conducted for the once receptor (seasonally-used dwellings) identified at 650 meters from the mine site.

Analysis of residual impacts in terms of a change to baseline levels is not applicable to vibration. This is because baseline conditions for existing vibrations cannot be established. Ambient vibration levels are normally near zero.

Ground Vibration Emissions and Model Assumptions

Blast-induced ground vibrations, both surface and body (underground) waves, naturally attenuate (reduce) with increased distance from the blast site. This is

due to material damping and geometric spreading. Body waves attenuate more rapidly than the surface waves. This results in the surface waves being more dominant at greater distances. The vibration intensity perceived or measured at the closest off-site structures around the TFM mine site would be dominated by surface waves.

The intensity of ground vibrations, which is an elastic effect measured in units of peak particle velocity, is defined as the speed of excitation of particles within the ground resulting from vibratory motion. For the purposes of this report, peak particle velocity is measured in millimeters per second.

The rate at which ground vibrations attenuate from a blast site is dependent on several variables, including:

- Characteristics of the blast (delay timing, type of explosive, etc.).
- Topography of the site.
- Characteristics of the bedrock and/or soil materials.

As mining operations have not yet started, there is no site-specific ground vibration monitoring data from the TFM site. The magnitude of blast vibrations from the open pit blasting operations at the neighboring properties were predicted using generalized attenuation equations available in published literature. The intensity of ground vibrations from blasting operations are primarily a function of the maximum explosive weight detonated (set off) per delay period and the distance between the blast and the receptor. The rate at which ground vibrations decay or attenuate from a blast site can be expressed by the scaled distance, which is defined as:

$$\text{Scaled distance (SD)} = D/\sqrt{W}$$

Where:

D = distance (meter) between the blast and receptor

W = maximum weight of explosive (kilogram) detonated per delay period

Prediction of maximum ground vibrations can be calculated based on the following equation (ISEE 1998):

$$PPV = 1725(SD)^{-1.6}$$

Where:

PPV = peak particle velocity (millimeters per second)

SD = scaled distance

The scaled distance equivalent for a peak ground vibration limit of 12.5 millimeters per second would be the square root of 21.7 kilograms per meter. From this, maximum explosive weights per delay period can be calculated for varying distances from the blast (Table C2.9-14). As this is a generalized equation based on the results from numerous mining and construction applications, attenuation characteristics for the TFM project will be better defined once blasting begins.

Table C2.9-14 Maximum Charge for Ground Vibration Guidelines to be Met by Differing Receptor Distance

Distance between Blast and Receptor (m)	Maximum Calculated Explosive Weight/Delay Period (kg) for 12.5 mm/s
500	530
600	764
650[(a)]	897
700	1,040
750	1,194
800	1,359
850	1,534
900	1,720

[(a)] Distance for identified receptor.
m = meter.
kg = kilogram.
mm/s = millimeters per second.

Airborne Vibration Emissions and Model Assumptions

The planned blasting charge levels in Table C2.9-13 will result in airborne vibration. The airborne vibration levels are measured in linear decibels (dBL) which attenuate with distance from the blasting site, similar to airborne noise. Airborne vibration levels predicted using a linear attenuation model.

Airborne vibrations attenuate from a blast site at a slower rate than ground vibrations. The distribution of air vibration energy from a blast is also strongly influenced by the prevailing weather conditions during the blast. Other factors influencing air vibration distribution from a blast include:

- The length of collar and type of stemming material.
- Differences in types of explosive material.
- Variations in burden distance.

The rate at which air vibrations decay or attenuate from a blast site can be expressed by the scaled distance, which is defined as:

Scaled distance (SD) = $D/3\sqrt{W}$

Where:

D = distance (meter) between the blast and receptor

W= maximum weight of explosive (kilogram) detonated per delay period

Prediction of maximum air vibrations was based on the following equation (ISEE 1998) which assumes average burial of the explosive:

$$P = 20\log10[(SD)-1.1] + 170.75$$

Where:

P = peak air pressure (dBL)

SD = scaled distance (meter per kilogram 0.33)

The scaled distance equivalent for the more stringent peak air pressure guideline of 120 linear decibels would be the cubed root of 203 meters per kilogram. Maximum charge weights per delay can then be calculated for varying distances from the blast site. This calculation is similar to the calculations for peak ground vibration levels discussed previously (Table C2.9-15).

Table C2.9-15 Maximum Charge for Airborne Vibration Guidelines to be Met by Receptor Distance[(a)]

Distance Between Blast and Receptor (m)	Maximum Calculated Explosive Weight/Delay (kg) for 120 dBL
500	239
600	414
650 [(b)]	527[(c)]
700	658
750	810
800	982
850	1,178
900	1,399

[(a)] Represents worst case scenario.
[(b)] Distance for identified closest receptor.
[(c)] US limit for a receptor 650 meters away.
m = meters.
kg = kilograms.
dBL = linear decibels.

Mitigation

The introduction of a surface miner eliminates the need to drill, blast and primary crush the ore. No additional mitigation or controls specific to vibration are required. Blasting will be designed and conducted in a controlled manner to maximize efficiency. Pit walls will also act as a barrier for airborne vibration. Impact assessment of later stages of mine development, including the Goma pit development, may require different mitigation responses. These will not be known until details of later stages of mine development become available and supplementary environmental studies have been conducted. The results in Table C2.9-15 are from a worst case scenario when the blast is at the surface without the mitigating effect of pit walls at a time when the pit excavation is just starting.

Results

While a number of permanent communities presently exist around the TFM mine site at distances exceeding 3,000 meters, the closest structures have been identified as huts used seasonally by farmers. These huts are about 650 meters from the south edge of the proposed Kwatebala pit. It is evident from the equations (discussed above) that the distance from the blast and the amount of explosive detonated per delay period within each blast are the critical parameters in controlling groundborne and airborne vibration effects.

As seen in Table C2.9-13, the maximum explosive weight detonated per delay period proposed for the TFM project would range between about 30 to 45 kilograms. These weights are considerably less than the 897 kilograms (Table C2.9-14) and 527 kilograms (Table C2.9-15) weights calculated to meet the peak limits for ground and air vibration levels of 12.5 millimeters per second vibration and 120 linear decibels, respectively, at the closest off site receptor. Calculated peak ground and air vibration levels that might be produced at the closest receptor, based on a worst-case minimum distance of 650 meters and a maximum explosive weight per delay of 45 kilograms would be less than 1.5 millimeters per second and 113 linear decibels, respectively. This compares with groundborne criteria of 12.5 millimeters per second (US Guideline – see Table C2.9-5) and airborne guidelines of between 120 linear decibels and 134 linear decibels (DRC, U.S. and Canadian guidelines – see Table C2.9-6). DRC limits are the most restrictive at 120 linear decibels. This suggests that the entire pit may be mined while maintaining the ground and air vibration limits contained in the US (OSMRE) guidelines. Vibrations from mining of the pit will also meet DRC and Canadian guidelines.

Impact Analysis

While a number of permanent communities presently exist within the LSA at distances exceeding 3,000 meters, the closest structures have been identified as those within a seasonal town to the south. These structures in the seasonal towns are about 650 meters from the south edge of the proposed mine pit. It is evident from the equations (discussed above) that the distance from the blast and the amount of explosive detonated per delay period within each blast are the critical parameters in controlling ground and air vibration effects. Calculated peak groundborne vibration levels that might be produced at the closest receptor, based on a worst-case minimum distance of 650 meters and a maximum explosive weight per delay of 45 kilograms, would be less than 1.5 millimeters per second. This suggests that the entire pit may be mined while meeting all applicable and reference standards, including those contained in the DRC mine regulation.

These results show that the amount of vibration generated at the nearest receptor, taken to be at 650 meters from the blast, is well below the guidelines. Since the amount of vibration is below the guideline, the magnitude of vibration effects is negligible. The residual impacts from vibration are provided in Table C2.9-16.

Table C2.9-16 Residual Impact Classification for Key Question V-1

Indicator	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
V-1: What effect will the project have on vibration?							
airborne vibration	negative	negligible	local	medium-term	reversible	medium	negligible
ground vibration	negative	negligible	local	medium-term	reversible	medium	negligible

The calculated maximum groundborne vibration levels likely to be produced at the closest off-site properties are expected to be perceptible to inhabitants. This is because people can perceive ground vibration intensities as low as 0.2 millimeters per second. Research, however, has established that a person can perceive, and may even be bothered by, ground vibrations with an amplitude as little as one one-hundredth of that required (within the same frequency range) to cause cosmetic defects to buildings. This often accounts for people to thinking that the shaking experienced from ground vibrations may affect the integrity of their homes. While a particular level of vibration may be perceptible to within the LSA, it is evident that the vibration levels can still remain well below damaging levels.

Prediction Confidence

There is a significant "cushion" between predicted levels and criteria levels to indicate that impacts are likely to be low, in other words there is a moderate to high confidence that levels predicted will be less than the criteria. This confidence does not imply a specific level of confidence about the accuracy of the predicted values which is controlled by site conditions and model algorithms. Confidence about predicted values will come from future site monitoring that can validate model predictions.

The quality and relevance of predictions in the assessment is dependant on the data inputs. For the assessment, vibration sources were established using client-supplied data regarding the expected blasting methods, project description data including area geology and professional judgment. Where assumptions were required regarding the generation of vibration energy, the option that would result in the greatest amount of vibration was selected.

Monitoring and Follow Up

A one-time groundborne and airborne vibration monitoring study for the Kwalabala pit should be done prior to the start of blasting operations at Goma to develop site-specific vibration attenuation characteristics. This monitoring would include:

- Establishing a series of seismographs at varying distances from several production blasts.
- Establishing seismographs at location near heavy traffic area and surface miner.
- Keeping a detailed record of the loading parameters.

During the Goma mine phase, the monitoring program would apply to Goma only as there is a potential for significant impacts at Goma that appear absent at Kwatebala.

The seismographs should be capable of measuring and recording full waveform ground vibration records in each of three orthogonal directions as well as simultaneously monitoring and recording air concussion effects.

Site-specific vibration decay characteristics developed could then be used to better predict maximum groundborne and airborne vibration intensities during subsequent blasting operations such as at Goma or as part of the expanded project. Once site-specific decay rates have been better defined the need for additional monitoring can be evaluated.

C2.9.4 Cumulative Effects Assessment

Noise

The impact assessment for the TFM project was conducted as a cumulative case, with all project elements calculated within one model set-up. Figures C2.9-3 and C2.9-4 show the cumulative noise impacts from all project elements during the Kwatebala mine phase.

The Goma and Fwaulu ore bodies are planned to be developed when mining activity at the Kwatebala pit is near completion in 2016 with Goma active from 2017 to 2020 and again in 2025 and Fwaulu active from 2020 to 2022 and again in 2027.

The development of these ore bodies would produce noise from both the mining activity in the pits, materials transportation associated with the mining and ore processing.

The impact of mining Goma and Fwaulu ore bodies has been quantitatively assessed. Future development of the Fungarume ore body has not been assessed as plans are not available.

Assessment Approach

As new ore bodies are mined subsequent to Kwatebala the mining fleet will be located closer to various receptors than before. Table C2.9-17 identifies locations where noise levels from the mining fleet may increase as each ore body is mined.

Table C2.9-17 Cumulative Effects Assessment – Noise

Ore Body	Village Locations Where Mining Activity May Increase Noise Levels
Goma	Tenke, Mulumbu Kiasa, Mwanga Sangu
Fwaulu	Tenke, Mulumbu Kiasa, Mwanga Sangu
Fungurume	Fungurume, Bloc Mitumba, Kafwaya, Mwela Mpande Gare

Quantitative assessment of Goma and Fwualu involved modeling the operations so that the noise levels produced could be predicted at all the identified receptors. The approach to prediction modeling and the description of the model used is in Section C2.9.3.4 under the heading Assessment Methods.

Noise Sources Associated with Goma and Fwaulu Mining

Details of the sources modeled are shown in Table C2.9-18.

Table C2.9-18 Noise Sources for Kwatebala, Goma and Fwaulu

Source	Type of Source[a]	Sound Power (dBA)[b]
Plant Site		
area 20 grinding	point	107
area 30 leach feed	area	109
area 40 CCD[c]	area	110
area 50 neutralization and tails	area	104
area 60 solvent extraction	area	109
area 70 copper electrowinning	area	113
area 80 cobalt recovery	area	114
area 90 sulfuric acid plant	area	109
area 103 dolomite	point	102
area 104 lime	point	92
area 105 magnesia storage and mixing	area	106
area 106 sodium hydroxide and mixing	area	93
area 110 potable/gland water	point	109
area 111 air compressor	point	114
area 112 boiler house	area	83
conveyors	line	121
plant light vehicle	line	81
plant fork lift	line	116
plant delivery truck	line	100
plant mobile crane	line	111
Mine Site		
Goma ore pit (including surface miner)	area	126 (year 2018)
Goma waste rock facility	area	122 (year 2018)
Goma stockpiles	area	124 (year 2018)
Fwaulu ore pit (including surface miner)	area	126 (year 2022)
waste pile fleet CAT773F	line	115[d]
ore fleet CAT770	line	113[d]
stockpile fleet CAT773F	line	115[d]
Quarry		
Mofia quarry	area	117
Public Roads		
highway trucks	line	107
highway light vehicle	line	81.3

[a] The type of source indicates how the emission was represented in the model. Area sources spread the emission over the relevant site for the activity, line sources move the sources along a given trace (e.g., roads) and point sources are a designated stationary location.

[b] dBA = A-weighted decibels

[c] CCD = countercurrent decantation

[d] Sound power level per equipment unit (e.g. each CAT773F)

Modeling for Goma and Fwaulu includes the following components:

- Goma pit activities are split into three mining areas inside the pit; Shimpidi, Kabwe and Goma with different extraction rates and times as shown in Table C2.9.19.
- Overall noise sources include mine activity, transportation of ore to stockpiles, transport of waste rock, transport of goods to and from external locations, quarry transportation and mine processing activities.
- Modeling for obstructions such as waste rock piles, material dumping areas, mine buildings and the general terrain.
- Activities at Goma and Fwaulu are modeled separately because they are not in operation simultaneously.
- Earth berms acting as noise barriers for mine haul truck noise along pit access roads.

Table C2.9.19 Extraction Rate for Mining Zones within Goma Pit

Goma Mining Areas	Percentage of Total Mined for Goma Ore Body			
	2017	2018	2019	2020
Kabwe (1 & 2)	52%	49%	77%	4%
Shimbidi	48%	36%	7%	8%
Goma	0%	14%	17%	88%

Modeling Scenarios and Assumptions

The modeling scenarios were:

- Modeling for a representative year (2018) when the Goma pit was active with no earth berm constructed for mitigation reasons between the pit and the nearest receptors in Tenke.
- Modeling for a representative year (2018) when the Goma pit was active and including a three meter high earth berm between the pit and the nearest receptor in Tenke.
- Modeling for a representative year (2018) when the Goma pit was active and including a five meter high earth berm between the pit and the nearest receptor in Tenke.
- Modeling a representative year (2022) when the Fwaulu pit was active.

The modeling assumptions were:

- The numbers of mine excavation vehicles such as the CAT 772 was in proportion to the amount of material planned to be mined compared with the Kwatebala 2010 production rate and vehicles in use.
- Unladen trucks assumed to travel at 50 kilometers per hour and laden trucks at 30 kilometers per hour.
- Assumed frequency for delivery vehicles.
- Mine pits modeled as area sources and roads as line sources.

Results

Table C2.9-20 shows the predicted noise levels at each of the receptors for the following mine development scenarios:

- Case 1A - Noise in 2018 from mining activities for the Goma Pit without additional mitigation measures.
- Case 1B – Noise in 2018 from mining activities for the Goma Pit with three meter high strategic berms.
- Case 1C - Noise in 2018 from mining activities for the Goma Pit with five and ten meter high strategic berms.
- Case 2 – Noise in 2022 from mining activities in Fwualu Pit without additional mitigation.

Table C2.9-20 Predicted Noise Levels for Goma and Fwaulu

Location of Receptor	Case 1A		Case 1B		Case 1C		Case 2		WBG	Night
	Project	Combined	Project	Combined	Project	Combined	Project	Combined	Guideline	Baseline
Kafwaya	8	44	8	44	8	44	8	44	45	44
Mwela Mpande Gare	19	44	19	44	19	44	19	44	45	44
Kwatebala Gare	26	44	26	44	26	44	26	44	45	44
Bloc Mitumba	22	44	22	44	22	44	22	44	45	44
Fungurume	36	44	36	44	36	44	36	44	45	43
Mulumbu Kiasa	34	44	34	44	34	44	40	46	45	44
Mwanga Saugu	34	44	34	44	34	44	42	46	45	44
Salabwe	33	44	33	44	33	44	40	45	45	44
Mwanga Muteba (South)	32	44	32	44	32	44	36	45	45	44
Mwanga Muteba (West)	32	44	32	44	32	44	36	45	45	44
Tenke 1	**46**	**47**	43	44	43	44	30	39	45	39
Tenke 2	**53**	**53**	**51**	**52**	**49**	**50**	32	40	45	39
Tenke 3	**46**	**47**	45	**46**	45	**46**	30	40	45	39

Project: Noise level from project sources only.

Combined: Noise level from project sources plus background.

Bold values represent exceedences of WBG guidelines.

The results show that there is potential for noise levels exceeding the project criteria at all three Tenke locations. The nature and design of mitigation measures to reduce levels at the Tenke receptors to comply with WBG guidelines (night-time of 45 A-weighted decibles will be determined after monitoring results are available from the Kwatebala mine as these will better reflect site conditions, the level of impact and sources of concern to be addressed by mitigation.

Discussion of Results

The receptors at Tenke are as close as 300 meters from the Goma pits. At that distance, noise levels from the mine are likely to be higher than for any of the other receptors that are more distant. Where the predicted noise levels, including both the existing noise and noise from the mine, are close to or above the WBG criteria it is important to consider the results of the proposed monitoring program at Kwatebala. This program will allow for a more accurate prediction of the noise levels at the Tenke receptors. This is because the results of monitoring will reflect actual site conditions, such as the level of noise from the plant and equipment used in the mine, and take into account the local characteristics of the ground and terrain. Better quantification of the source and extent of any impact will lead to a more effective mitigation design.

Noise for other receptors and from activities at Fwaulu are expected to fall below the WBG guidelines.

Vibration

With blasting activity located at the Goma and Fwaulu ore bodies the distance to the nearest assessment point changes from 650 meters for Kwatebala to 300 meters, which is the distance from Goma to the Tenke 2 receiver.

Assessment-of Groundborne Vibration

The assessment procedures described at C2.9.3.5 under Assessment Methods and the blast design details in Table C2.9-13 are followed here. The assessment methodology is as outlined under C2.9.3.5 Ground Vibration Emissions and Model Assumptions.

With a known distance of 300 meters and the US EPA criteria of 12.5 millimeters per second peak particle velocity, the charge weight required to equal the criteria value at 300 meters is 190 kilograms. The maximum charge weight planned is 30 to 45 kilograms.

Vibration – Airborne Blast Wave

The assessment procedures described at C2.9.3.5 under Assessment Methods and the blast design details in Table C2.9-13 are followed here. The assessment methodology is as outlined under C2.9.3.5 Airborne Vibration Emissions and Model Assumptions.

With a known distance of 300 meters and applying the DRC criteria of 120 linear decibels the weight of charge needed to equal this criteria value at 300 meters is 51.65 kilograms. The maximum charge weight planned is between 30 to 45 kilograms.

Results

The planned charge weight is less than the charge weight needed to exceed either the groundborne and/or airborne criteria (Table C2.9-21).

Table C2.9-21 Comparing Charge Weight to Equal Ground and Airborne Criteria at 300 Meters with Project Planned Charge Weight.

Criteria	Charge Weight Predicted to Equal Criteria at 300 m	Project Planned Charge Weight
groundborne - 12.5 mm/s peek particle velocity	190 kg	30-45 kg
airborne – 120dB(L)	51.6 kg	30-45 kg

m = meters.
kg = kilograms.
mm/s = millimeters per second.

Monitoring

Monitoring of noise and vibration from the Kwatebala pit and associated facilities will be needed to plan mitigation to address potential cumulative impacts of the Goma and Fwaulu mine pits.

One round of monitoring for noise at Kwatebala is recommended prior to the start of mining at Goma. This will validate noise predictions to date and increase the certainty of predictions at the Tenke receptors as local conditions that affect the propagation of noise will then be included. Any resulting adjustments will improve the accuracy of predicted noise levels from both the Goma and Fwaulu pits. Additional monitoring for noise may also be necessary to address any noise concerns or complaints raised by people affected. The recommended locations and duration of noise monitoring are shown in Table C2.9-22 below:

Table C2.9-22 Recommended Noise Monitoring Location and Duration

Monitoring Location	Duration
Fungurume	24 hours
Mulumbu Kiasa	24 hours
Mwanga Saugu	24 hours
Salabwe	24 hours
Mwanga Muteba (Shungu)	24 hours
Tenke (Tenke 2 receptor locale)	24 hours
Kwatebala mine pit boundary	24 hours
Kwatebala mine pit equipment (e.g. surface minor, haul trucks)	short-term equipment emission measurement
Kwatabala waste rock facility	short-term equipment emission measurement
low grade ore and ROM stockpile	short-term equipment emission measurement

Monitoring for groundborne and airborne vibrations should be done at Kwatebala prior to the start of blasting operations at Goma to develop site-specific vibrations attenuation (decay) characteristics. This information can be used to better predict maximum groundborne and airborne vibration intensities for subsequent blasting activities.

C2.9.5 Conclusions

Noise

The effect of noise levels was 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.
- Evaluating the resulting noise levels at specific receptors.

Negligible impacts were predicted for the project activities associated with the Kwatebala ore body. This conclusion assumes that the three closest communities of Mulumbu, Amorú and Kiboko are relocated. All predicted noise levels met the WBG night-time guideline (45 A-weighted decibels) at the receptors identified for the assessment. The predicted noise levels also meet the reference DRC noise standard (40 A-weighted decibels at night). Baseline noise levels will also be unchanged at all locations except Fungurume, Mulumbu Kiasa, Mwanga Saugu, Salabwe, and Mwanga Muteba (Shungu). These changes are only expected to be one to two A-weighted decibels. Since WBG criteria are met, and only negligible changes in baseline noise levels are expected, the effects of noise

caused by the TFM project during the Kwatebala mine phase are considered to be of negligible environmental consequence (Table C2.9-23).

Table C2.9-23 Summary of Residual Classification for Key Question N-1

Location	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
$N_{(ce)}$-1: What effect will the project have on noise levels near project activities?							
all receptors	negative	negligible	local	medium-term	reversible	high	negligible

Noise impacts will change as mining progresses to future ore bodies within the RSA. For activities associated with the Goma and Fwaulu ore bodies noise levels are close to the WBG criteria for receptors on the outskirts of Tenke, about 300 meters from the Goma mine. There are no predicted impacts at other receptors from either Goma or Fwaulu. Noise monitoring at Kwatebala is recommended. The results of this monitoring will allow application of actual site conditions to the Goma predictions, ensuring a more accurate mitigation design. Actual site conditions can then be also applied to noise predictions for any future mine expansions such as for the Fungurume ore body.

Vibration

The effect of project vibration levels were determined by:

- Establishing the control distance to receptors that would represent a worst-case scenario.
- Establishing the magnitude of a blasting charge that would equal the criteria at the worst-case distance and at other distances.
- Comparing the level of charge from this analysis to the project`s planned charge.

Negligible impacts were predicted (Table C2.9-24) as all planned weights of charge for the project were considerably less than the maximum charge weight able to comply with both groundborne and airborne criteria obtained from the US (groundborne) and from the DRC, Canada and the US (airborne). This outcome applies to the Goma and Fwaulu ore bodies as well as for Kwatebala.

Table C2.9-24 Summary of Residual Impact Classification for Key Question V-1

Indicator	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
$V_{(ce)}$--1: What effect will the project have on vibration?							
airborne vibration	negative	negligible	local	medium-term	reversible	medium	negligible
ground vibration	negative	negligible	local	medium-term	reversible	medium	negligible

As mining extends to new ore bodies such as for Fungurume, villages in the areas affected will become significant receptors. The potential for impact will depend on:

- Extent and design of blasting.
- Distance and terrain characteristics between mine and village and the application of mitigation.
- Implementation of mitigation measures.

Monitoring is recommended to establish site-specific vibration decay characteristics so that future impacts can be better predicted.

C2.10 HYDROGEOLOGY

C2.10.1 Introduction

This section presents the environmental assessment for the effects of the Tenke Fungurume Mining (TFM) project on groundwater. The information presented in this section meets the requirements of the terms of reference for the project (Appendix E8) and includes details on:

- Components within each phase of the project that may influence or affect groundwater resources and/or groundwater quality.
- Impact assessment for the potential impact of the project on the groundwater system.
- Concerns identified by stakeholders and regulators regarding groundwater impacts.
- Sustainability assessment for groundwater issues.
- Proposed mitigation measures to be considered during the construction, operation and reclamation phases of the project to minimize groundwater-related effects.
- The monitoring program that will be used to identify and monitor project impacts on groundwater levels and quality.

This section is organized as follows:

- Section C2.10.2 describes the study areas.
- Section C2.10.3 discusses the approaches and results for the impact and sustainability assessments.
- Section C2.10.4 discusses the cumulative effects assessment.
- Section C2.10.5 discusses the conclusions of the impact assessment.

Regional climate, hydrologic and hydrogeological information has been compiled to characterize the groundwater baseline conditions in the study area. The baseline information is presented in Sections B2.7, B2.11 and B2.10. The available baseline information is used in this section to evaluate the potential effects of the TFM project on the local and regional groundwater system.

A glossary of terms and acronyms used in this section is provided at the end of this volume.

C2.10.2 STUDY AREAS

Figures of the study areas and the descriptions for the hydrogeological assessment are provided in Section C1.4. The Regional Study Area (RSA) covers large parts of the Dipeta and Mofia river catchments and a lesser part of the Tshilongo River catchment. Proposed and potential future mining activities in the TFM concession will occur within these areas.

The RSA covers the aquifers contained within the Mofia and Dipeta river catchments, upstream of the airstrip and Fungurume, respectively. These two catchments were selected since potential impacts resulting from mining operations at Kwatebala Hill will be limited to the aquifers associated within these two river systems and their respective catchments. The mining activity will generally straddle the topographic divide (which is likely a groundwater divide) separating the two catchments. The waste rock facilities, the tailings storage facility and the processing plant will be located within the Mofia catchment.

The area where mining and its associated activities have the potential to directly impact groundwater is the Local Study Area (LSA) (see Figure C1.4-1). The mine is located in the upper Dipeta River catchment. The airstrip, limestone quarry and construction camp/permanent village will be located in the Kabomboy River catchment. Changes in these catchments also have the potential to impact on the groundwater system. Construction and operation of access roads have the potential to cause localized effects in a number of other catchments of the Mofia and Dipeta rivers.

After approximately nine years of mining at Kwatebala, the Goma (approximately year 2017) and Fwaulu (approximately year 2020) hills are proposed to be mined. Mining of the Goma and Fwaulu pits may impact aquifers associated with the Tshilongo River catchment. Analysis of these impacts will be completed before mining those hills.

C2.10.3 Impact Assessment

C2.10.3.1 Issue Scoping

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 rock facilities, a tailings storage facility and other facilities. These disturbances will result in changes in runoff and infiltration (groundwater recharge). Storm

water from areas designated as “contact” (impacted by process materials) within the plant site will be collected and used in the process water circuit.

The construction of the tailings storage facility, the waste rock facilities and ore stockpiles will result in changes in infiltration to groundwater. The tailings storage facility liner will result in reduced infiltration over the tailings storage facility area. Infiltration may remain unchanged or slightly increase below waste rock facilities and ore stockpiles due to hydrological conditions within the facilities during mine operations. Post-closure infiltration to groundwater will be limited by the soil and vegetation cover that is placed on the facilities as part of reclamation.

Mine water supply will be drawn from the wells around the mine, which will also serve as dewatering wells. The use of groundwater will affect local groundwater resources and may also reduce the discharge of groundwater to springs and surface water (baseflow). A post-closure pit lake will develop in the closed open pit. This pit lake will affect the groundwater conditions once mining has ceased.

The project has the potential to affect the groundwater system as a result of several activities, including:

- Site construction and grading, resulting in changes in runoff and infiltration and potential reduction in groundwater recharge.
- Groundwater use for water supply purposes and subsequent effect on the hydrogeological system, including reduced groundwater levels and a reduction in groundwater discharge to springs and surface water.
- Mine dewatering and subsequent effects on the hydrogeological system, including reduced groundwater levels and a reduction in groundwater discharge to springs and surface water.
- Seepage from the tailings storage facility, waste rock facilities, ore stockpiles and associated pollution control dams and effects on groundwater quality.
- Accidental process liquid or material spills and effects on groundwater quality.
- Development of a post-mining pit lake and the associated changes in the long-term groundwater system.

A number of concerns relating to potential changes in the quantity (availability) and quality of groundwater were noted during the public consultation process (Section A6). These include:

- The accumulation of heavy metals in groundwater, both from the TFM project as well as cumulative effects from previous mining operations in the area.
- Impacts on water quality by releases from the tailings dam, effluent dams, or releases of effluent from the processing plant.
- The interruption of groundwater flow and potential impacts on the continued use and availability of well water by communities for domestic use, for livestock and for irrigation.
- Concern regarding changes to spring flows by the project, and consequent effects on the water supply for local communities.

The linkages between project activities and potential effects on groundwater are shown in Figure C2.10-1. Potential groundwater impacts could occur during all phases of the project and may result in a permanently altered groundwater system. The key questions used to guide this assessment are also shown. Results of this assessment that were used in another section of the environmental and social impact assessment (ESIA) for the TFM project are also shown.

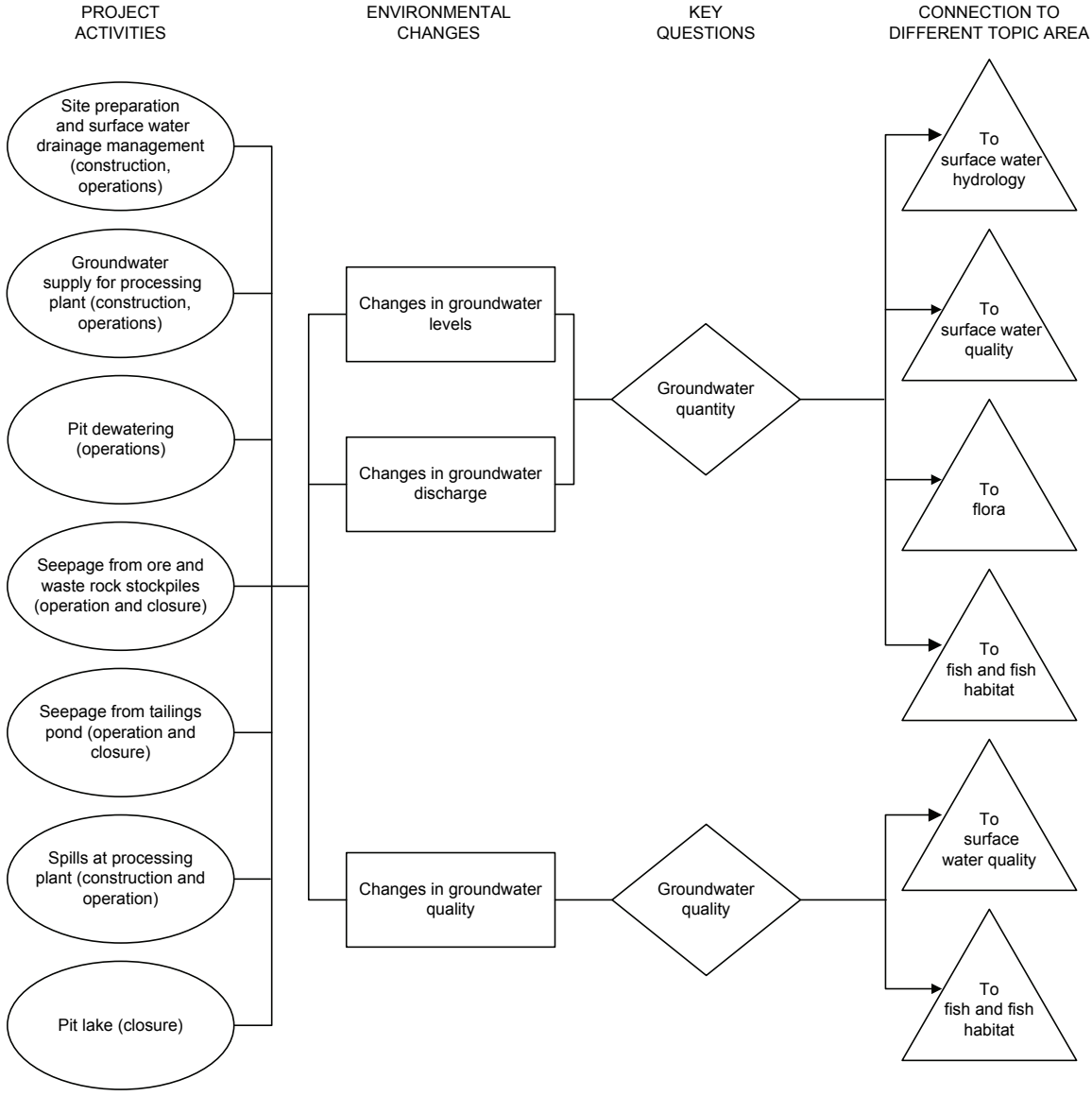
C2.10.3.2 Key Questions and Indicators

The linkages shown in Figure C2.10-1 were assessed by answering key questions (with Sub-questions) for groundwater (Table C2.10-1). The use of linkage analysis and key questions is described in Section A5.

Table C2.10-1 Key Questions for Groundwater

Impact Assessment	
GW-1	What effect will the project have on groundwater resources including groundwater levels, groundwater availability and groundwater discharge to springs and surface water (baseflow)? Specifically, a) How will mine facilities (tailings storage facility, waste rock facilities, ore stockpiles and the processing plant area) affect groundwater recharge quantities? b) How will groundwater use for process make-up water affect groundwater resources? c) How will groundwater use for pit dewatering affect groundwater resources? d) How will the post-closure pit lake affect groundwater resources?
GW-2	What effect will the project have on groundwater quality? Specifically, a) How will seepage from mine facilities (tailings storage facility, waste rock facilities, ore stockpiles, and the processing plant area) affect groundwater quality? b) How will the post-closure pit lake affect groundwater quality?
Sustainability Assessment	
GW-3	How can the project have a long-term benefit on groundwater quantity and quality?

Figure C2.10-1 Groundwater Quality Linkage Diagram



The Global Reporting Initiative (GRI 2005b) and the International Federation of Consulting Engineers (FIDIC 2006) have identified indicators for water quantity and water quality. Table C10.2-2 provides a description of these indicators and how these have been adapted for use in the ESIA.

Table C2.10-2 Indicators for Groundwater Quantity and Quality

GRI Indicators	FIDIC Indicators	ESIA Indicators
Groundwater Quantity		
EN20 ▪ water sources and related ecosystems/habitat significantly affected by use of water		▪ changes in groundwater levels and streamflow ▪ effect of changes in recharge on groundwater levels and baseflow discharge to springs and streams
EN5 ▪ total water use	EN13 ▪ measurements of water usage on project during all phases	▪ changes in groundwater levels and streamflow ▪ effect of changes in recharge on groundwater levels and baseflow discharge to springs and streams
EN22 ▪ total recycling and reuse of water EN21 ▪ annual withdrawals of ground and surface water as a percent of annual renewable quantity of water available from the sources		▪ changes in groundwater levels and streamflow ▪ effect of water use for processing and dewatering on groundwater levels and baseflow to springs and streams
Groundwater Quality		
	EN14 ▪ measurement of BOD on waterbodies affected by project during all phases	• analysis of total coliforms and E.coli in groundwater affected by the project during all phases ▪ measurement of cations and anions and mineral salts in the groundwater system ▪ major cations and anions and metal salt concentrations not to exceed protection drinking water guidelines at compliance points for the project

BOD = biological oxygen demand.

Sources: Global Reporting Initiative (GRI 2005b).
International Federation of Consulting Engineers (FIDIC 2006).

C2.10.3.3 Assessment Criteria

The assessment criteria used for hydrogeology are presented in Table C2.10-3.

Table C2.10-3 Impact Description Criteria and Numerical Scores for the Tenke Fungurume Mining Project – Hydrogeology

Resource	Direction[a]	Magnitude[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
groundwater	**positive**, **negative** or **neutral** for the measurement endpoints	**negligible**: less than 5 percent change **low:** 5 to 10 percent change **moderate**: 10 to 30 percent change **high**: greater than 30 percent 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**: less than 3 years **medium-term**: 3 to 20 years **long-term**: greater than 20 years	**reversible** or **irreversible**	**low**: occurs rarely **medium**: occurs intermittently (less than 10 times per year) **high**: occurs frequently (10 or more times per year)

[a] Direction: positive or negative effect for measurement endpoints, as defined for 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 two-year construction period and a 20-year operation period.

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

[f] Frequency: how often the environmental effect occurs.

C2.10.3.4 Key Question GW-1

Key question GW-1 is: What effect will the project have on groundwater resources including groundwater levels, groundwater availability and groundwater discharge to springs and surface water (baseflow)?

Linkage Evaluation

Figure C2.10-1 shows the linkage between project activities and potential effects. The linkages associated with key question GW-1 are described in this section. Project activities during construction, operation and closure may result in changes in the groundwater system. Linkages are further evaluated by the sub-questions below.

Sub-question GW-1a

Sub-question GW-1a is: How will mine facilities (tailings storage facility, waste rock facilities, ore stockpiles and the processing plant area) affect groundwater recharge quantities?

As part of mine construction, vegetation and soil will be removed. Grading will occur to reshape the topography. Mine facilities, such as the processing plant, will be constructed on engineered surfaces (concrete pads). The tailings storage

facility will be lined with a low-permeability liner. Waste rock facilities and ore stockpiles will be placed on existing sub-grade soils. Remaining exposed soil in areas of disturbance may be compacted to provide vehicle passage (informal, temporary roads). Artificial drainage channels and detention dams/ponds will be constructed to manage storm water runoff from the mine facilities. These construction activities will modify the runoff and infiltration characteristics within the mine area. Changes in infiltration will affect the groundwater resources in the project area.

Construction activities may increase or decrease the amount of infiltration that would reach the groundwater system depending on how the water is managed. Directing runoff from impervious (cannot be penetrated) areas, such as roofs and concrete pads, to local drains or vegetated areas may locally increase recharge. Similarly, directing runoff directly to surface water via ditches would decrease groundwater recharge at the processing plant site during mining operations.

Following reclamation, overall groundwater recharge is expected to be similar to existing conditions. However, areas underlain by a low permeability liner (tailings storage facility, landfill areas) will have reduced groundwater recharge. .The tailings storage facility liner will reduce the amount of groundwater recharge occurring in the Kasana catchment (tributary to Mofia catchment) during mine operation and closure. During mine operation, groundwater recharge may remain unchanged or it may increase above pre-existing conditions below the waste rock facilities and ore stockpiles. This is because of the absence of vegetation on the waste rock facilities and ore stockpile surface and the presence of relatively permeable soil underlying these facilities. Seepage passing through these facilities would infiltrate into the subsurface. Following reclamation of the waste rock facilities, or any unprocessed ore stockpiles, groundwater recharge will be similar to existing conditions. This will be due to the placement of a soil cover (similar to existing conditions) over the facilities, combined with a vegetative layer to enhance runoff and transpiration from the soil zone. Reclamation of the soils beneath the ore stockpiles would occur following re-processing of ore stockpiles. Under reclaimed conditions, recharge is expected to return to pre-mining conditions.

Sub-question GW-1b

Sub-question GW-1b is: How will groundwater use for process make-up water affect groundwater resources?

For the purpose of this ESIA, the water supply for the mining operation (process make-up water) is assumed to be provided by a new wellfield constructed near Kwatebala and integrated with mine dewatering operations. Hydrologic

investigations, including the drilling and pumping of test wells, have verified that a groundwater supply source exists near the Kwatebala mine site, adequate to supply the process make-up water needs. Pump test data from these same wells were also used to estimate the amount of water that may be required for mine dewatering purposes. A groundwater flow model was constructed in order to simulate the effects of withdrawing water for both process water use and dewatering of the Kwatebala open pit (Appendix C2.10-I).

The production/dewatering wellfield will be installed in phases, starting as a part of the mine construction. These dewatering wells will be operated from Year 0 onward to provide the mine's water supply, including construction water. Dewatering of the open pit will not be required until about Year 8 of operation, meaning that the dewatering wells will be pumped only to meet the demand for process water during the first seven years. It is expected that the mine dewatering wells will provide sufficient water for construction activities and process operations. However, as a contingency, additional wells may be developed near the mine, and/or the existing Fungurume wells will be rehabilitated to provide the necessary supply.

The current estimated maximum demand for process water make up is 450 cubic meters per hour (10.8 million liters per day or 125 liters per second). Demand will reduce to an estimated annual average of 224 cubic meters per hour (5.4 million liters per day or 62 liters per second) once recycling process water from the tailings storage facility and storm water dams begins. This water demand represents about 14 percent of the combined annual average flow of the Dipeta and Mofia Rivers as measured at the Lower Dipeta and Lower Mofia gauges (Section B2.11). This calculation assumes no return of the mine open pit dewatering water to tributaries of the Mofia and Dipeta Rivers. Much of this water will be returned to the rivers, either as excess water not required for processing operations or as part of a surface water mitigation program to supply water to stream reaches affected by the pit dewatering program. These actions will reduce the potential flow reduction in the rivers.

Pumping the dewatering wells will lower the water level in the borehole causing groundwater to flow toward the wells and a "cone of depression" to develop around the dewatering wells. The amount of drawdown in the dewatering wells and the shape and extent of the cone of depression will be a function of the nature and distribution of geological units, the hydraulic properties of the geological units (transmissivity and storativity), and the dewatering rate. The greatest drawdown will occur at the dewatering wells with the amount of drawdown decreasing with distance from the wells.

Any existing wells and springs within the cone of depression would be affected by the dewatering operations. Water levels could drop in the wells, potentially reducing well yield if the well is relatively shallow. Deeper wells with significant saturated thickness would see a water level decline and consequent lower pumping water level, and a decrease in the maximum yield. A decrease in groundwater levels at spring sites could result in reducing spring flow or drying up a spring under an extreme condition. If dewatering lowers the groundwater level below the elevation of the river, then there will be a reduction in surface water flow. This reduced surface water flow will be due to the infiltration of surface water into the groundwater system. If dewatering results in a lowering of groundwater levels (but not below the surface water elevation), then there will be a reduction in the amount of groundwater discharged as baseflow to surface water.

The hydrogeological investigation was designed to collect the necessary information to determine the properties of the aquifers for input into a groundwater flow model. A groundwater flow model (Appendix C2.10-I) was then used to determine the impacts of groundwater use for mine water supply and pit dewatering on the groundwater system. The study also evaluated the water supply well locations.

Sub-question GW-1c

Sub-question GW-1c is: How will pit dewatering affect groundwater resources?

Mine pit dewatering will not be required until about Year 8 of mining. Assuming that the dewatering wells are installed in Year 0 and fully provide the project's process water needs, these wells will be pumped at a rate of 5.4 million liters per day for the period before the open mine pit reaches the water table. As the mine pit deepens, a greater quantity of groundwater must be pumped to keep the mine pit bottom dry, the pit slopes well drained, and to enable mining operations to proceed efficiently. At some time it is likely that the dewatering requirements will exceed the water required for process purposes. Once this occurs, dewatering water in excess of the process requirements will be discharged to the local surface water drainage system. The water quality assessment (Section C2.12) states that the dewatering water is expected to be similar in quality to the springs.

The discharge of excess dewatering water will occur in the headwaters of the tributary streams draining the mine area that may become impacted by dewatering. The principal potentially-affected streams are the Kasana, Shimpidi and the Sokalwela (Section C2.11). Some of this excess water will infiltrate, but most will become surface runoff, providing surface water for human use and support of riparian vegetation (including gallery forests) (Section C3.1). This

mitigation measure will also lessen impacts to fish and aquatic habitats (Section C3.3).

The open pit dewatering operations will affect the groundwater system in a manner similar to that described for the groundwater supply (Section C2.10.3.4 Sub-question GW-1b). The hydrogeological investigation was designed to collect the necessary information to develop a groundwater flow model that was used to determine the mine pit dewatering requirements and the effects of dewatering on the groundwater system.

Sub-question GW-1d

Sub-question GW-1d is: How will the post-closure pit lake affect groundwater resources?

Following mining, the dewatering wells will be turned off and the groundwater level will rise and flood the mine pit. Surface water runoff from the pit slopes will also enter the mine pit contributing to the rise in the water level in the pit. Over time, the water level in the mine pit will reach an equilibrium level dictated by the pit topography, groundwater conditions and water balance (the inflows-groundwater, surface water and precipitation and outflows-evaporation and groundwater discharge). The post-mining pit lake water elevation will rise above the pit floor, and will likely be slightly lower than the pre-mining groundwater levels (see Appendix C2.10-I). This change could affect the groundwater system surrounding the mine. Changes in the groundwater system could include changes in the groundwater levels and discharge levels of groundwater to springs. Changes to baseflow in the local rivers could also result.

Assessment Methods

To determine the impact of the mine and associated facilities on the groundwater system, a scientific assessment was conducted. The assessment included three phases:

1) A preliminary study of existing information and site reconnaissance to develop an overall conceptual model of the groundwater system.
2) A field work investigation phase to fill data gaps by drilling, installing, testing and sampling monitoring and production wells to characterize the site conditions.
3) An analysis phase to evaluate and interpret the data, to revise the conceptual model and to conduct an impact assessment using appropriate modeling tools. The three phases are outlined below.

Preliminary Study

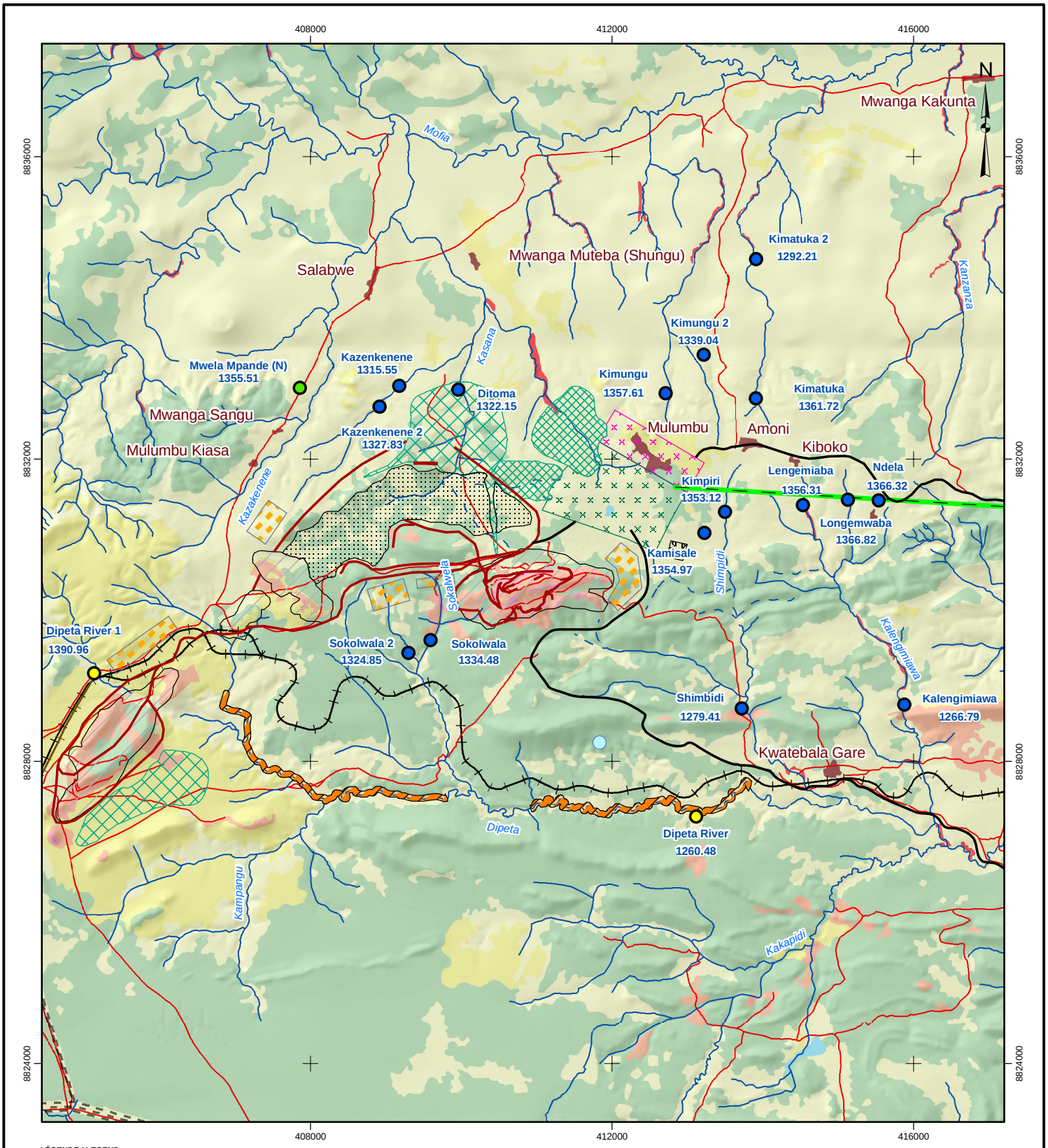
- A literature review of existing geological and hydrogeological information available for the TFM concession area.
- A hydrocensus (groundwater reconnaissance), which required identifying the location of all the springs and boreholes mentioned in previous literature, as well as any others, in order to confirm the existing information on groundwater level and flows. The hydrocensus was followed by sampling groundwater from selected springs and boreholes (Figure C2.10-2). The samples were analyzed by an accredited laboratory in Johannesburg, South Africa.
- Development of a hydrogeological conceptual model.

Investigation Phase

- Completion of a geotechnical investigation to characterize the shallow hydrogeological conditions.
- A geophysical survey to confirm the existence of structural features interpreted from satellite photographs and to locate targets for monitoring and test wells.
- Installation of groundwater monitoring wells at mine facilities.
- Exploration drilling on target sites identified during the geophysical survey to investigate the groundwater conditions.
- Test pumping selected boreholes to determine aquifer characteristics such as transmissivity, storativity and boundary conditions.

Analysis and Impact Assessment Phase

- Analysis of the hydrological information to estimate groundwater recharge.
- Analysis of the pumping test data to determine the hydraulic properties of the key geological units in the project area.
- Development of an updated conceptual hydrogeological model of the mine area.
- Construction of a numerical groundwater flow model based on the conceptual hydrogeological model to determine the impact on the groundwater system from:
  - Groundwater supply for processing.
  - Pit dewatering.
  - Seepage from the waste rock, ore and tailing pond.
  - Post-mining pit lake.



LÉGENDE / LEGEND

- FORAGES (NON ÉCHANTILLONNÉS) / BOREHOLES (NOT SAMPLED)
- PUITS DE SURFACE ET FORAGES / DUG WELL AND BOREHOLES
- RIVIÈRE / RIVER
- SOURCE / SPRING
- LIGNE DE TRANSPORT D'ÉNERGIE / POWERLINE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- AUCUN ÉCOULEMENT DE SURFACE / NO SURFACE FLOW

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

COUVERTURE VÉGÉTALE / UTILISATION DU TERRAIN / LANDCOVER

- AFFLEUREMENT ROCHEUX DE MINERAI CUIVRE-COBALT - COMPLEXE EXPLOITÉ PAR L'ACTIVITÉ MINIÈRE ARTISANALE / COPPER-COBALT ROCK OUTCROP - ARTISANAL MINING COMPLEX
- STEPPE-SAVANE SUR SUBSTRAT CUPRO-COBALTIFÈRE / COPPER-COBALT STEPPE-SAVANNA
- FORÊT DE MIOMBO / MIOMBO WOODLAND
- FORÊT DE MIOMBO DÉGRADÉE / MIOMBO WOODLAND DEGRADED
- FORÊT GALERIE / GALLERY FOREST
- ZONE HUMIDE / WETLAND
- MOSAÏQUE AGRICOLE / AGRICULTURAL MOSAIC
- ANCIENNE JACHÈRE / OLD FALLOW FIELD
- AÉROPORT / AIRFIELD
- PERTURBATION / DISTURBANCE
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

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ÉCHELLE 1:70000 KILOMÈTRES
SCALE 1:70000 KILOMETERS

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE **DISTRIBUTION SPATIALE DES SOURCES ET DES FORAGES, RECENSEMENT DES RESSOURCES EN EAU SOUTERRAINE DE JANVIER 2006 / DISTRIBUTION OF SPRINGS AND BOREHOLES HYDROCENSUS JANUARY 2006**

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035		ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	GJ	22 Jun. 2006	
GIS / SIG	KL	04 Jan. 2007	
VÉRIFIÉ / CHECK	MR	20 Oct. 2006	
APPROUVÉ / REVIEW	MR	20 Oct. 2006	

FIGURE: C2.10-2

Project: I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\mxd\Tenke_ESIA\Volume_C\FigureC2.10-2_SpringDistribution.mxd - Plot: I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\pdf\Tenke_ESIA\Volume_C\FigureC2.10-2_SpringDistribution.pdf

- The groundwater flow model for the Kwatebala open pit, tailings and waste rock stockpiles is described in Appendix C2.10-1.
- Development of an analytical groundwater transport model to evaluate the potential impacts on groundwater quality from waste rock facilities/ore stockpile seepage and tailings storage facility seepage. The analytical groundwater transport model is described in Appendix C2.12-I.

Mitigation

Several engineering elements have been incorporated into the project design to minimize the effects of the project on groundwater resources (Section D3.1-6). These mitigation measures include:

- Storm water runoff from the processing plant and other project facilities during construction and operations will be directed to retention/detention ponds and used in the plant process. This will minimize the potential degradation of groundwater quality.
- During operations, the tailings storage facility will be developed in stages, which will minimize the loss in groundwater recharge from the fill covering the natural ground surface.
- The groundwater process supply/pit dewatering well system will be designed to minimize drawdown impacts on local wells, springs and surface water during mine operations.
- The pit dewatering system will be operated to maintain the groundwater level just below the bottom of the mine pit as the pit is deepened. This will provide dry mining conditions and improved slope stability. It will also minimize the drawdown effects outside the mine pit.
- Excess pit dewatering water will be discharged to surface water during mine operations to augment stream flow, as needed. Water will only be released if it meets applicable quality guidelines. Stream flows will be monitored to determine if and when flow augmentation is required.
- The Fungurume wellfield will be upgraded, if needed, to supply the construction camp/permanent village water needs. During mine operations, local individuals would be trained to run the water system. Upon closure of the mine the wellfield infrastructure would be handed over to the local population to provide a long-term water supply.
- Basic groundwater supply systems (involving a well with a mechanical hand pump) will be provided to villages where spring water sources are affected by the use of groundwater for process water or mine pit dewatering.

Results

Figure C2.10-3 shows the location of the mine facilities and their setting with respect to the local watershed boundaries. Figure C2.10-4 shows the location of the mine facilities with respect to the aquifer systems.

Numerical Groundwater Modeling for Groundwater Resources Impacts

A groundwater flow model has been prepared to evaluate the impacts to groundwater resources from the TFM mining operations. The model is described in Appendix C2.10-I.

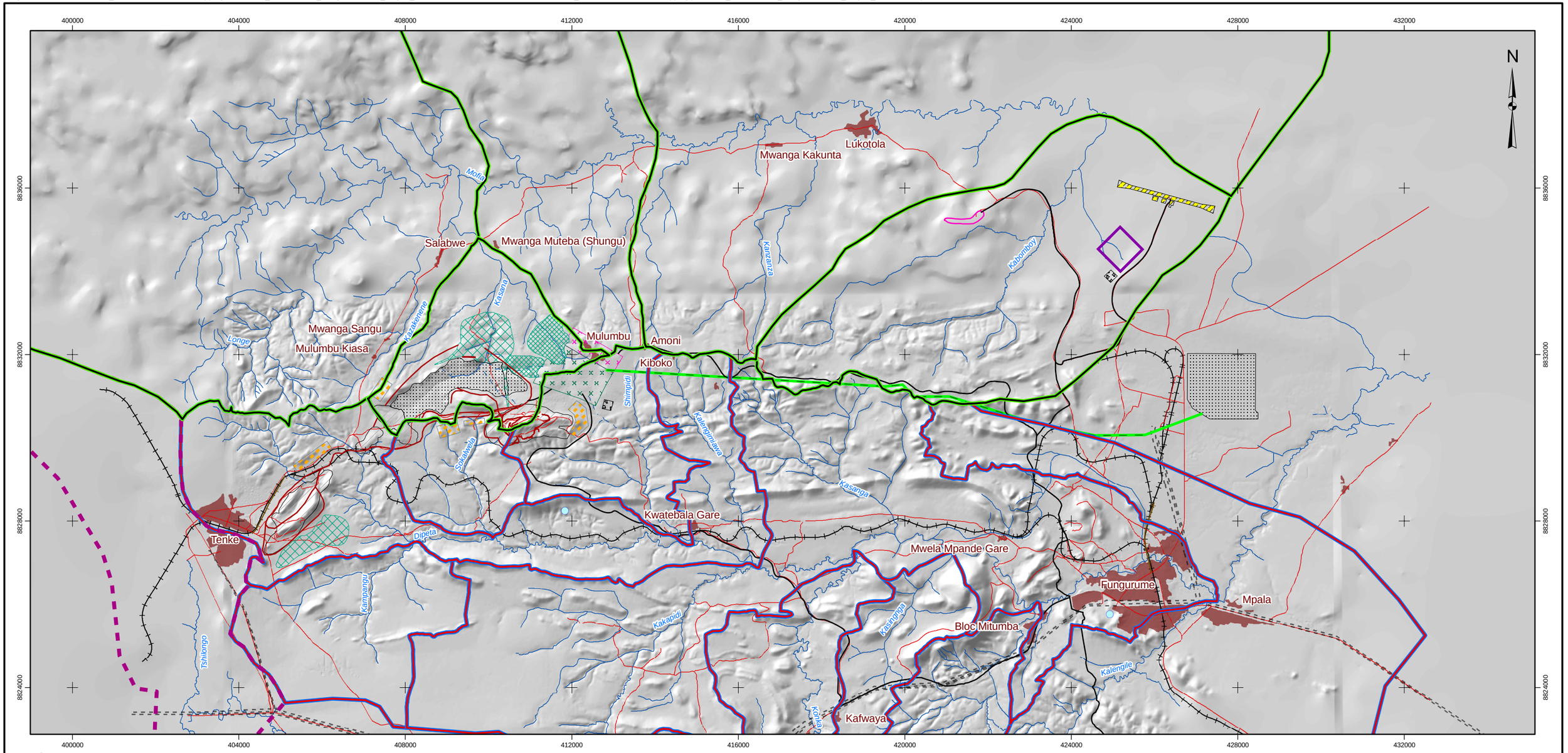
Model output provides a quantitative assessment of the potential range of impacts to groundwater resources based on test well installation and testing, from investigation of the tailings storage facility area, the water supply investigation, and development of the water balance model. The model also explores the sensitivity of the predictions to variations in geologic interpretations and changes to the mining/dewatering plan. The model impact analysis results are therefore presented as a range of potential impacts. Figures and tables depicting the model results are presented in the groundwater modeling appendix (Appendix C2.10-I). The results are summarized briefly below:

Pit Inflows/Dewatering

Model results suggest that groundwater inflow to the pit will increase over time as the pit is deepened, commencing in Year 8 and reaching flow rates that could range from about 200 liters per second (720 cubic meters per hour) to potentially as much as 650 liters per second (2,340 cubic meters per hour) at the end of the mining process. Inflows are, however, more likely to be toward the lower end of the range.

Impacts of Dewatering on Groundwater Levels and Baseflow

The area affected by one meter or more of drawdown is estimated to be between about 100 and 160 square kilometers. Without mitigation the baseflow in the Dipeta River near Fungurume could decrease from about 240,000 cubic meters per day pre-mining to 200,000 cubic meters per day at the end of the operational phase. However, much of this decrease would be mitigated during the mining operation phase through returning excess dewatering water to tributaries to the Dipeta.



LÉGENDE / LEGEND

- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

BASSINS VERSANTS / CATCHMENTS

- DIPETA
- MOFIA
- TSHILONGO

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

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ÉCHELLE / SCALE 1:90000 1:90000 KILOMÈTRES / KILOMETERS

PROJET / PROJECT

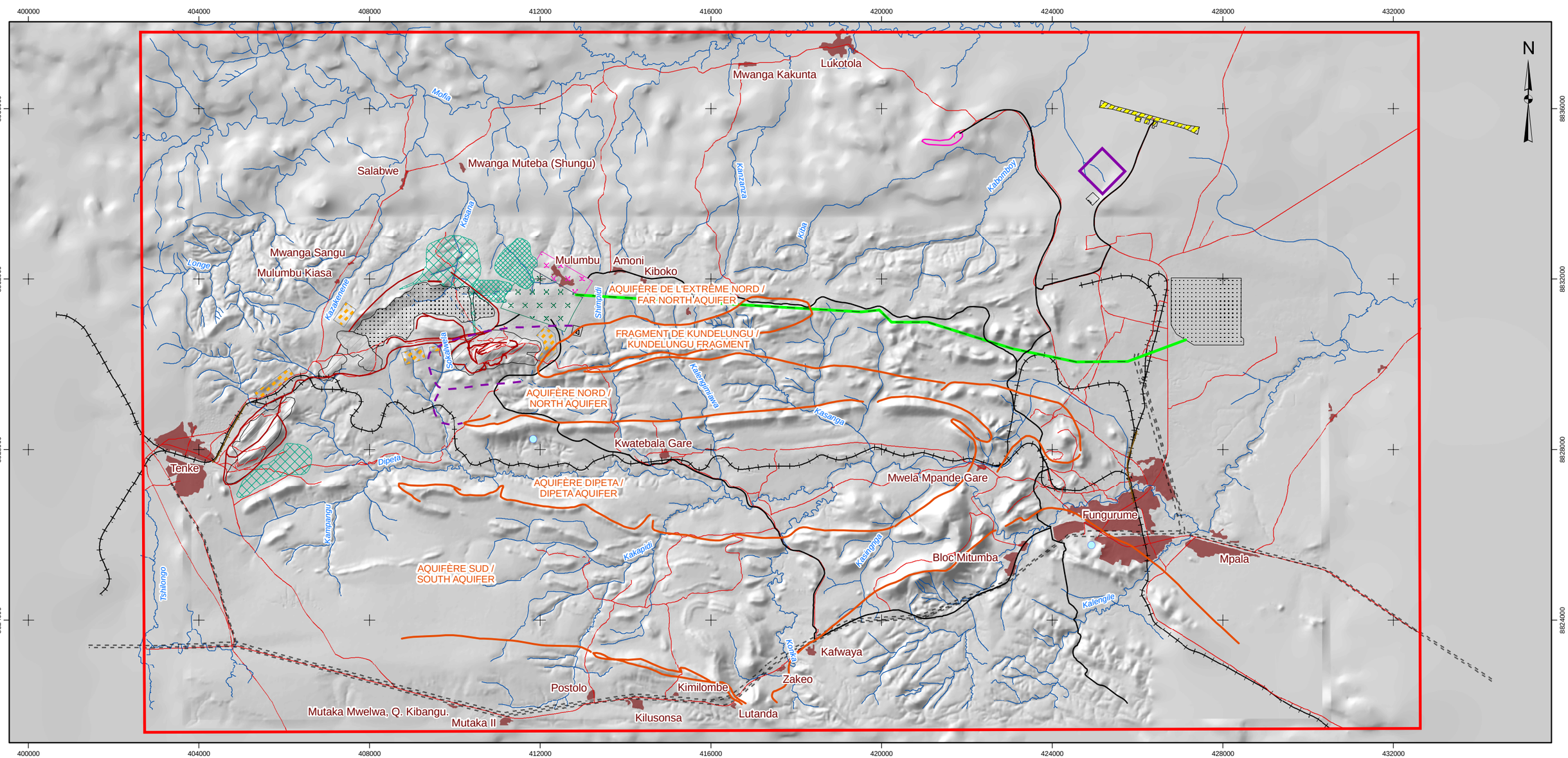
PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE **SECTEUR DU PROJET PAR RAPPORT AUX BASSINS VERSANTS / PROJECT AREA RELATIVE TO CATCHMENTS**

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	TR	15 May 2006		
GIS / SIG	KL	04 Jan. 2007		
VÉRIFIÉ / CHECK	MR	24 Oct. 2006		
APPROUVÉ / REVIEW	MR	24 Oct. 2006		

FIGURE: C2.10-3



LÉGENDE / LEGEND

- FRONTIÈRE PRÉSUMÉE DE L'AQUIFÈRE / INFERRED AQUIFER BOUNDARIES
- FRONTIÈRE PRÉSUMÉE DE L'AQUIFÈRE À ÉTUDIER / INFERRED AQUIFER BOUNDARIES TO BE INVESTIGATED
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- ZONE D'ÉTUDE RÉGIONALE / REGIONAL STUDY AREA

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE 1:90000 KILOMÈTRES
SCALE 1:90000 KILOMETERS

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE **INSTALLATIONS DU PROJET EN RELATION AVEC LES AQUIFÈRES / PROJECT FACILITIES IN RELATION TO AQUIFERS**

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035		ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	GJ	22 Jun. 2006	
GIS / SIG	KL	04 Jan. 2007	
VÉRIFIÉ / CHECK	MR	24 Oct. 2006	
APPROUVÉ REVIEW	MR	24 Oct. 2006	

FIGURE: C2.10-4

Impacts of Dewatering and Groundwater Supply on Wells and Springs and Gallery Forest

- **Springs and Wells -** There could be adverse impacts to local springs and wells used by the community for water supply purposes. The impacts will be progressive, gradually increasing over the duration of pit dewatering and then extend into the closure and post-closure period as the groundwater system re-establishes to a new equilibrium. It is predicted that 15 to 16 springs in the vicinity of the mine could be temporarily lost as a source of supply during the mining period. Over the long-term post-closure period, no springs are predicted to stop flowing completely; however, several springs will show only seasonal rather than year- round discharge.
- **Gallery Forest -** There could be impacts on the groundwater levels below areas of gallery forest sustained by groundwater discharge. The impacts will be progressive, gradually increasing over the duration of pit dewatering and then extend into the closure and post-closure period as the groundwater system re-establishes to a new equilibrium. The impacts would be greatest in the Kasana drainage north of the waste rock stockpile and similar north-flowing tributaries reaching the Mofia River in proximity to the mine.

Post-Closure Pit Lake Effects on Groundwater System

The groundwater flow model indicates that the post-closure water level elevation in the pit will be below the lip of the pit. There will therefore be no surface water overflow from the pit. The pit will discharge groundwater to the local flow systems.

Once mining and dewatering cease the recovery in the groundwater levels will form a pit lake within the open pit. The modeling indicates that the pit lake water level will recover to a new equilibrium level 20 to 60 years following the end of mining.

The results of the groundwater resources impact assessment are presented in Table C2.10-4. This table lists each mine facility or area and its potential impact on groundwater resources (groundwater levels, groundwater availability, discharge to springs and baseflow) and groundwater quality. The watershed in which the impact could occur is also included in the table. The table then includes an assessment of the potential relative magnitude of the impact based on a scale as follows:

0 – Little, if any, impact.

1 – Negligible localized impact.

Table C2.10-4 Mine Facilities and Their Potential Effect on Groundwater Resources

Facility	Area (ha)	Affected Sub-Watershed/ Aquifer Unit	Effect on Groundwater Resources
water supply/ pit dewatering wells	100 to 160 (km^2)	Shimpidi, Kasana and Sokalwela/ Far North Aquifer, North Aquifer/Dipeta Aquifer	Processing plant supply/dewatering wells and pit dewatering will lower groundwater levels over an area ranging from 100 to 160 square kilometers potentially affecting nearby wells, and reducing groundwater discharge to about 15 to 16 springs and surface water during mining. There will be a small residual effect post-closure. impact = -2 to -3 (operations) 0 to -1 (post-closure)
tailings storage facility	233	Kasana/Far North Aquifer	Covering of soil with low-permeability liner will reduce infiltration and groundwater recharge. This reduction in recharge will affect baseflow in the Kasana drainage. The reduction will be throughout mining and post closure. impact = -1 to -2 (operations) -1 to -2 (post-closure)
return water pond[(a)]	20	Kasana/Far North Aquifer	Covering of soil with liner will reduce infiltration and groundwater recharge during mining. The pond will be reclaimed at closure returning conditions to pre-mining. impact = -1 (operations) 0 (post-closure)
waste rock facilities	145	Kasana/Far North Aquifer	Potential increase in groundwater recharge during operations. little change from pre-existing conditions at closure because of placing of soil cover and vegetation. impact = +1 (operations) 0 (post-closure)
ore stockpile (east)	77	Kasana/Far North Aquifer	potential increase in groundwater recharge during operations No change at closure because stockpile removed and site reclaimed. impact = +1 (operations) 0 (post-closure)
ore stockpile (west)	38	Kasana/Far North Aquifer	Potential increase in groundwater recharge during operations. No change at closure because stockpile removed and site reclaimed. impact = +1 (operations) 0 (post-closure)
run of mine stockpile	6	Kasana/Far North Aquifer	Potential increase in groundwater recharge during operations. No change at closure because stockpile removed and site reclaimed. impact = +1 (operations) 0 (post-closure)
processing plant site	30	Shipidi and Kasana/ Far North Aquifer and North Aquifer	Potential reduction in groundwater recharge from increased impervious surfaces during mining. No change at closure because facilities removed and site reclaimed. impact = -1 (operations) 0 (post-closure)
pit lake (post-closure)	143	Shimpidi, Kasana and Sokalwela/ Far North Aquifer, North Aquifer/Dipeta Aquifer	Potential effect on groundwater recharge because of increased capture of surface runoff plus the evaporation from open pit water surface at post closure. impact = -1 to +1

[(a)] Estimated.

n/a = not applicable.

ha = hectares.

2 – Moderate localized impact.

3 – High local and regional impact.

A negative number indicates an adverse groundwater impact such as poorer water quality or a reduced quantity of available groundwater. A positive number indicates a beneficial groundwater impact such as increased groundwater recharge. This scale has been used to provide an assessment based on the known site conditions, existing information (such as seepage water quality and quantity) and based on experience at similar mining sites.

An assessment of the potential changes in recharge as a result of mine facilities has been made based on existing information. The results of this preliminary assessment are presented in Table C2.10-5.

The analysis indicates that there could be an overall change in groundwater recharge in the Kasana catchment from the tailings storage facility, waste rock and ore stockpiles and the process plant ranging from a loss of 21 percent to a potential net gain of over 70 percent (during mine operation). Overall, the change in groundwater recharge in the Mofia catchment would range from a decrease of one percent to an increase of four percent. There could be little if any change in the Shimpidi catchment or potentially a small increase in groundwater recharge associated with the infiltration of non-contact stormwater (such as roof runoff) from the process plant area (MinProc 2007). The range in impacts in both catchments is associated with uncertainty in the estimates of pre-mining groundwater recharge.

At post-closure, the groundwater recharge from all facilities except the tailings pond would be the same as existing conditions because the facilities would be removed and/or covered with similar soil and vegetation compared to existing conditions. Groundwater recharge will be less than existing conditions under the tailings pond. This reduced groundwater recharge will contribute to a net loss of recharge of about 23 percent in the Kasana catchment and about one percent in the Mofia catchment. There would be no change in post-closure recharge in the Shimpidi catchment because the process plant would be reclaimed consistent with existing conditions.

Table C2.10-5 Changes in Recharge from Mine Facilities During Mining and Post Closure

Watershed or Catchment	Total Watershed Area (ha)	Groundwater Recharge Existing Conditions (mm/yr)		Groundwater Recharge Existing Conditions (m^3/yr)		Mine Facility		Groundwater Recharge (mm/yr)		Change in Groundwater Recharge during Mining (mm/yr)		Change in Groundwater Recharge to Watershed During Mining (m^3/yr)		Change in Groundwater Recharge to Watershed During Mining (%)		Change in Groundwater Recharge Post-Closure (mm/yr)		Change in Groundwater Recharge to Watershed Post Closure (m^3/yr)		Change in Groundwater Recharge to Watershed Post Closure (%)	
		Max	Min	Max	Min		Footprint Area (ha)	During Mining	Post Closure	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Kasana		250	150			Tailings Pondtailings pond	233	9E-05	9E-05	-250	-150	-5.8E+05	-3.5E+05			-250	-150	-5.8E+05	-3.5E+05		
Kasana		250	150			Reclaim Water Pond[(a)]reclaim water pond[(a)]	20	7	200	-243	-143	-4.9E+04	-2.9E+04			0	0	0.0E+00	0.0E+00		
Kasana		250	150			Ore Stockpile (east)ore stockpile (east)	77	286	200	36	136	2.8E+04	3.2E+05			0	0	0.0E+00	0.0E+00		
Kasana		250	150			Ore Stockpileore stockpile (west)	38	356	200	106	206	4.0E+04	4.8E+05			0	0	0.0E+00	0.0E+00		
Kasana		250	150			Waste Rock Dumpwaste rock facility	145	261	200	11	111	1.6E+04	1.6E+05			0	0	0.0E+00	0.0E+00		
Kasana		250	150			ROM StockpileROM stockpile	6	284	200	34	134	2.0E+03	3.1E+05			0	0	0.0E+00	0.0E+00		
Kasana		250	150			Process Plant Siteprocess plant site	15	238	200	-12	88	-1.8E+03	2.1E+05			0	0	0.0E+00	0.0E+00		
Total Kasana Watershed	**1,030**	250	150	2.6E+06	1.5E+06		**534**					-5.5E+05	1.1E+06	**-21**	**71**			-5.8E+05	-3.5E+05	**-23**	**-23**
Upper Mofia	**16,100**	250	150	4.0E+07	2.4E+07		**534**							**-1**	**5**					**-1**	**-1**
Shimpidi		250	150			Process Plant Siteprocess plant site	15	238	200	-12	88	-1.8E+03	2.1E+05			0	0	0.0E+00	0.0E+00		
Total Shimpidi Watershed	**1,200**	250	150	3.0E+06	1.8E+06		**15**					-1.8E+03	2.1E+05	**0**	**11**			0.0E+00	0.0E+00	**0**	**0**
Total Mid Dipeta	**10,600**	250	150	2.7E+07	1.6E+07		**15**							**0**	**1**					**0**	**0**

Notes:

Process plant site assumed to be equally divided between KasanaProcess plant site assumed to be equally divided between Kasana and Shimpidi watersheds

Recharge rates for ore, waste rock and ROM stockpiles and plant site from Water Balance Modeling - Report No : 7908/8467/13/W

Tailings seepage seepage rate 2.00E-01 m^3/y.

Source - Section 9.10.5.4 - tailings tailings study.

(a) Seepage from reclaim water reclaim water pond during operations

Source - tailings WB 100ktpa - 2006_07_03 from D. Walker

Plant site, reclaim pond, ore site, reclaim pond, ore stockpile and ROM pads removed at closure and areas reclaimed

mm/y = millimeters per year.

m^3/y = cubic meters per year.

min = minimum.

max = maximum.

A similar assessment of the effects of using the Fungurume wellfield to meet the construction camp/permanent village water demand has been made based on the existing data. A range of transmissivity and storativity values was selected to represent the likely conditions at the wellfield. The pumping rate was assumed to be 500,000 liters per day. The pumping duration is one year. Recharge is sufficient to replenish the aquifer annually. The analysis (Table C2.10-6) indicates that pumping the wellfield would theoretically lower the groundwater levels over several kilometers from the wellfield. However, measurable drawdown would only be detected within 1,000 meters of the well. The amount of drawdown would be limited because of the high transmissivity of the aquifer. Springs located within this area of drawdown could potentially be impacted if they are in hydraulic connection with the main aquifer, but the change in flow is likely to be undetectable.

Table C2.10-6 Estimated Range in Drawdown at Fungurume Wellfield from Construction Camp Water Use

Scenario	Aquifer Hydraulic Properties	Aquifer Drawdown at Distance from Wellfield (m)		
		100	1,000	10,000
1	transmissivity 2,000 m^2/d storativity 1 x 10^{-4}	0.24	0.15	0.06
2	transmissivity 3,500 m^2/d storativity 1 x 10^{-3}	0.17	0.07	0.02

m^2/d = square meters per day.

Uncertainty in the potential impacts on groundwater resources is reflected in the range of aquifer hydraulic properties presented in Table C2.10-6.

Impact Analysis

This section presents an overall summary of the residual impacts to the groundwater system (groundwater resources) during operation and post-closure relating to key question GW-1.

Table C2.10-7 presents a summary of the residual impacts with regard to groundwater resources.

Table C2.10-7 Residual Impact Classification for Key Question GW-1

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question GW-1: What effect will the project have on groundwater resources including groundwater levels, groundwater availability and groundwater discharge to springs and surface water (baseflow)?						
Far North Aquifer (tailings storage facility, waste rock facilities, processing plant site, ore stockpiles)						
negative	moderate to high	local to regional	long-term	yes	high	moderate to high
North Aquifer (Kwatebala open pit mine, processing plant)						
negative	moderate to high	local to regional	long-term	yes	high	moderate to high
Dipeta Aquifer (no mine facilities)						
negative/ neutral	negligible to low	local	medium-term	yes	low	negligible to low
South Aquifer (no mine facilities)						
negative/ neutral	negligible to low	local	medium-term	yes	low	negligible to low
Tshilongo Catchment (no mine facilities)						
negative/ neutral	negligible to low	local	medium-term	yes	low	negligible to low

The residual (post-mitigation) impacts on groundwater resources in the Far North Aquifer and North Aquifer are negative in direction. This is because groundwater levels will decline in response to pumping. This will potentially reduce the water levels in local wells and reduce the groundwater discharge to springs and surface water close to the water supply/dewatering wells during mine operations and for a number of years during the start of mine flooding as groundwater levels recover to new equilibrium conditions. After a post-mining pit lake has developed there will likely be little long-term residual impact on groundwater resources.

The nearest known local well is at Mwela Mpande, located to the northwest of the mine site (Figure C2.10-2). It is predicted that water supply and mine dewatering could result in a drawdown of between 7 and 17 meters at this location at the end of mining (Year 20). Drawdown would be progressive over the life of the mine with little drawdown over the first eight years and then increasing during pit dewatering. It is estimated that 15 to 17 springs will be adversely affected by the dewatering operations and will stop flowing during mine operations. These decreases in spring discharge will affect the flow in the upper reaches of local rivers.

Based on current information and analyses, the magnitude of residual impacts would be moderate to high with the geographic extent ranging from local (in the

Kasana, Shimpidi and, possibly, the Sokalwela catchments) to regional (beyond the LSA) depending on the hydrogeological conditions. The overall regional impact will be low because the impact is small in relation to the overall water budget for the Dipeta and Mofia Rivers. The duration of impacts will be long-term, occurring for the life of the mine until post-closure.

The groundwater pumping/dewatering effects are considered reversible because pumping will cease at the end of mining. Groundwater levels will then recover to new equilibrium conditions, similar to pre-existing conditions. The frequency of the predicted effects is classified as high (continuous). The environmental consequence of the predicted effects is moderate to high depending on the quantity of groundwater removed during mine pit dewatering and the hydrogeological conditions near the pit.

The magnitude of the residual effects on groundwater resources in the Dipeta Aquifer and South Aquifer is negligible to low. These aquifers are not targeted for groundwater supply purposes but there is some potential for these aquifers to be impacted by groundwater pumping from the North and Far North Aquifers.

A possible positive residual impact could be the provision of higher quality (compared to current drinking water sources) potable (drinking) groundwater to affected villagers during mine operations. In addition, following mining, the groundwater supply system could be dedicated to the local authorities for domestic, agricultural or industrial use.

Prediction Confidence

The impact predictions regarding impacts to the groundwater resources are subject to some uncertainty because of the sensitivity of the model results to the interpreted geological conditions. The major source of uncertainty is the nature and extent of low-permeability units at the mine and their interaction with surface water and springs. This uncertainty is addressed by incorporating two different geological interpretations into the model and by presenting the results as a range rather than as a single-point estimate. It will be further addressed through operational monitoring of groundwater levels and spring flows surrounding the mine site.

Monitoring

A groundwater resources monitoring program (Section D3.1.6) will be implemented during operation and closure to determine the impacts on groundwater quantity and flow from the groundwater supply/mine dewatering

and seepage from mine facilities. The monitoring program will include the following elements:

- Recording the quantities of water pumped from each groundwater supply/dewatering well.
- Measuring the groundwater levels in the wells and in observation boreholes.
- Measuring the discharge from springs near the groundwater supply/dewatering wells.
- Measuring precipitation.
- Using piezometers installed in gallery forest habitats to monitor water levels, within the predicted cone of depression of the dewatering wells.
- Measuring the discharge in surface water (the Dipeta and Mofia rivers) as part of the hydrological monitoring program.

C2.10.3.5 Key Question GW-2

Key question GW-2 is: What effect will the project have on groundwater quality?

Linkage Analysis

Figure C2.10-1 shows the linkage between project activities and potential effects. The linkages associated with key question GW-2 are described in this section. Project activities during construction, operation and closure may result in changes in the groundwater quality. Linkages are further evaluated by the Sub-questions below.

Sub-question GW-2a

Sub-question GW-2a is: How will seepage from mine facilities (tailings storage facility, waste rock facilities, ore stockpiles and the processing plant area) affect groundwater quality?

There will be seepage from various mine facilities that could affect the quality of the underlying groundwater (Figure C2.10-1). These facilities include the waste rock facilities, the ore stockpiles and the tailings storage facility. The amount of seepage will be a function of the precipitation and evaporation conditions, the topography underlying the waste rock facilities and ore stockpiles, the grain size of the stockpile material, and/or the permeability of the underlying soils below the ore stockpiles and waste rock facilities or the permeability of the liner below the tailings storage facility. An estimate of the seepage quantities from these

facilities is presented in the water balance (MinProc 2007). C2.12. The quality of the seepage will be a function of the geochemistry of the waste rock, ore and tailings. Geochemical characterization of the seepage is discussed in Appendix B2.3-I.

A mass balance (flow rate and concentration) groundwater transport model has been prepared. This model and results are presented in Appendix C2.12-I. The model is based on:

- The configuration and expected physical conditions of the waste rock facilities and ore stockpiles.
- The permeability of the underlying soil to estimate the quantity and quality of seepage from the waste rock facilities and ore stockpiles.
- The concentrations of constituents in leachate generated by these facilities.

During mine operations, the seepage rate from the waste rock facilities and ore stockpiles is expected to be similar to, or possibly slightly greater than existing conditions (MinProc 2007). After the seepage migrates below these facilities, the water will pass through the underlying soil where some attenuation of metals may occur. Upon reaching groundwater, the seepage will mix and disperse within the groundwater system. The nature and extent of affected groundwater will be a function of the physical and chemical properties of the groundwater flow system, including:

- Thickness and hydraulic conductivity of the geological units.
- Hydraulic gradient.
- Effective porosity.
- Dispersivity.
- Redox conditions.
- Chemical partitioning between solute and rock mass.
- Background water quality.

Accidental chemical spills may also contribute to changes in the groundwater quality, depending on the nature, extent, frequency and duration of such spills, but these are likely to be a much smaller load to groundwater than the waste rock or ore stockpiles.

Sub-question GW-2b

Sub-question GW-2b is: How will the post-closure pit lake affect groundwater quality?

Following mining, the dewatering wells will be turned off and the groundwater level will rise, until the mine pit is flooded. Surface water runoff from the pit slopes will also enter the mine pit, contributing to the rise of the water level in the pit. The quality of water in the post-mining pit lake will be a function of the quality and quantity of the various water inputs to the pit lake and the effects of concentration from evaporation on pit lake water quality.

The post-mining pit lake could either be:

- An ultimate groundwater "sink" with groundwater and surface water flowing into the pit. Water inputs would be balanced by evaporation as there is no groundwater outflow from the pit. Under these circumstances, the equilibrium pit lake water level would be below the surrounding groundwater level. The pit lake would not have any effect on groundwater quality outside the pit.

  or

- The pit could become a groundwater "source" with the equilibrium pit water level higher than the surrounding groundwater level. Under these conditions, the water in the pit lake would flow out of the pit. This outflow would affect the groundwater quality surrounding the pit.

Assessment Methods

To determine the impact of the mine and associated facilities on groundwater quality, a scientific assessment was conducted. The assessment included three phases:

1. A preliminary study of existing information and site reconnaissance to develop an overall conceptual model of the groundwater system.
2. A field work investigation phase to fill data gaps by drilling, installing, testing and sampling monitoring and production wells to characterize the site conditions.
3. An analysis phase to evaluate and interpret the data, to revise the conceptual model, and to conduct an impact assessment using appropriate modeling tools.

These three phases were outlined under key question GW-1 covering groundwater quantity. The aspects related to the groundwater quality assessment are presented below.

Preliminary Study

- A literature review of existing geological and hydrogeological information available for the TFM concession area.
- Sampling of groundwater from selected springs and boreholes. The samples were analyzed by an accredited laboratory in Johannesburg, South Africa.
- A surface geophysical investigation program to identify major hydrogeologic features.
- Development of a preliminary hydrogeological conceptual model.

Investigation Phase

- Installation of groundwater monitoring wells at mine facilities.
- Exploration drilling on target sites identified during the geophysical survey in to order to probe the underlying lithologies.
- Test pumping selected boreholes to determine aquifer characteristics such as transmissivity, storativity and boundary conditions.

Analysis and Impact Assessment Phase

- Development of an updated conceptual hydrogeological model.
- Development of a numerical groundwater flow model to identify groundwater pathways and groundwater travel times to surface water from mine facilities and from the post-closure pit lake.
- Development of a geochemical model to determine the characteristics of seepage from the mine facilities.
- Development of an analytical groundwater transport model to evaluate the potential impacts to groundwater seepage from waste rock facilities/ore stockpile seepage, tailings storage facility seepage and the post-closure pit lake.

Mitigation

Several engineering elements have been incorporated into the project design to minimize the effects of the project on groundwater quality. These mitigation measures include:

- Storm water runoff from the processing plant site and other facilities will be collected and used in the process plant. This will minimize water quality impacts during construction and operations.
- The installation of underground tanks will be avoided.
- Secondary containment will be provided at all surface tanks and storage areas containing potential contaminants to minimize impacts.
- The tailings storage facility will be lined to minimize seepage of poor-quality water to groundwater during operations and closure.
- At closure:
  - All potential contaminants will be removed/drained from storage tanks and storage areas.
  - Potentially contaminated infrastructure will be removed.
  - The closure topography on the tailings storage facility and waste rock facilities will be contoured to minimize infiltration and seepage of poor-quality water to groundwater.
  - Vegetation will be established on the sides of the tailings storage facility, The top of the tailing facility will have a waste rock cover.
  - Vegetation will be established on the top of the waste rock facilities to reduce infiltration and seepage of poor-quality water.
  - Low-grade ore stockpile will have been fully processed at closure. The footprint of these stockpiles will be reclaimed.
- During construction, operations and closure an environmental action plan (Section D3.1.6) will be implemented that includes:
  - Groundwater water level and groundwater quality monitoring in boreholes and at springs to detect changes in groundwater levels associated with water supply/dewatering and groundwater quality.
  - Protection of springs from poor-quality runoff.
  - Immediate clean up of chemical spills.

Results

Modeling for Groundwater Transport

Geochemical Characterization and Groundwater Transport Modeling

The geochemical characterization of the mine wastes (Appendix B2.3-1) indicated that there were several constituents that had the potential to exceed standards or guidelines for drinking water and thus had the potential to result in the degradation of groundwater quality and limit future use. These constituents include:

- Sulfate from the waste rock , tailing seepage, and possibly the ore stockpile (although testing of the ore stockpile materials indicates slightly elevated but acceptable sulfate levels in the simulated storm water leachate).
- Nitrate from the waste rock and post-closure pit (due to blasting residues, ore materials will not be blasted).
- Arsenic from the tailing and ore seepage.
- Copper from waste rock and ore seepage.

Table C2.10-8 Groundwater Transport Modeling – Source Concentrations

Facility	Constituent Range in Seepage at Mine Facility (mg/L)			
	Sulfate	Nitrate (as N)	Arsenic	Copper
primary EPA drinking water standard	250[(a)]	10	0.01	1.0[(a)]
tailing storage facility *(Table 6.5-7)*	899 to 14,696	-	0.004 to **0.2**	0.01 to 0.1
waste rock facility *(Table 6.2.8)*	6.8 to **965**	**13**	<0.001 to 0.01	0.01 to **3.6**
ore stockpile *(Table 6.3-7)*	3.9 to 193	9	0.001 to **0.03**	0.02 to **24**
post-closure pit lake *(Table 6.4-3)*	13 to 68	**13**	0.003 to 0.01	0.02 to 0.1
background groundwater *(Appendix B2.10-1 - Table 2)*	1.3 to 94	0.4 to 1.2	**<0.02**	0.002 to 0.006

[(a)] Secondary standard.

Notes:

Table numbers refer to Confirmatory Mine Waste Characterization Study – Appendix B2.3-1.

N/S = no standard.

Bold = potential to exceed EPA drinking water standard.

The groundwater transport model evaluated the transport of constituents from their sources to surface water. Arsenic and copper are not mobile under the groundwater conditions at Tenke and can be considered to be fully attenuated

within a short distance of the source. This is because of the high retardation factor for these constituents. This analysis is shown in Appendix C2.12-I.

Sulfate and nitrate are mobile in groundwater and will migrate at the average linear groundwater velocity. In the long term with a continuous source such as the waste rock stockpile or pit lake, sulfate concentrations in groundwater downgradient of the source will rise to a steady-state concentration equivalent to or slightly lower than the source concentration. For a transient source, such as nitrate from the ore stockpiles, groundwater concentrations will rise during operations, and then decline as nitrate is flushed from the source at closure. Therefore, from a groundwater quality perspective, sulfate is the key constituent that could affect the use of groundwater supplies surrounding the mine facilities. Sulfate is not a toxic constituent, but is regulated as a secondary drinking water standard. Secondary drinking water standards are set based on aesthetic (taste and odor) requirements and are not health-based.

The area that could potentially be affected by the seepage of poorer quality water (elevated sulfate) from the mine facilities during mining and post-closure is shown on Figures 41 and 42 in the groundwater model appendix (C2.10-I). These figures do not indicate that all groundwater in these areas would exceed drinking water standards, only that there is a potential for an exceedance during mining and closure.

Seepage from the tailings pond has the greatest potential to result in an exceedance of water quality standards because of the high concentration in the pond. However, the pond is lined and seepage will be very small and thus subject to considerable dispersion in the groundwater system. Seepage from the waste rock facility has the potential to result in groundwater exceedances for sulfate and nitrate. Any nitrate exceedance is likely to occur close to the facility (within a few hundred meters) given that the predicted source concentration is 13 milligrams per liter as N and the drinking water standard is 10 milligrams per liter. For sulfate, potential water quality exceedance downgradient of the waste rock facility could extend a greater distance – as far as the discharge point to surface water (Kasana River or Mofia River) if sulfate concentrations approach the high end of the predicted source concentration. It should be noted that the leach tests also indicated that the sulfate concentrations decreased rapidly with successive leaching episodes. This indicates that the sulfate impacts may be transient and not representative of what would be expected after closure.

Seepage Pathways from Mine Facilities

Prior to dewatering (Years 0 to 8) seepage from the tailings facility and the southern part of the waste rock facilities and ore stockpiles will migrate to the

south and southeast (towards the Kwatebala pit) while seepage from the northern parts of the waste rock facilities and ore stockpiles will migrate towards the north and the Mofia River. Once dewatering commences (Year 8 or 9), seepage from the tailings facility will be captured by the pit. However, seepage from the northern parts of the waste rock facilities and ore stock piles will migrate to the Mofia River in the north.

The groundwater travel time to the Mofia River and the Kasana River tributary from the mine facilities varies from less than one year where the stockpile is located in a valley bottom and there is the potential for a discharge to the headwater tributaries to over 20 years where groundwater discharge is to the lower reaches of the Kasana River or to the Mofia River.

Post Closure Pit Lake Effects on Groundwater Flow System

The steady state post closure simulation shows that seepage from the mine facilities and pit lake could reach the Mofia and Dipeta Rivers. Under steady-state conditions, groundwater from the pit could reach the Dipeta River in about 12 to 16 years. The time for the pit lake to begin discharging to groundwater (through-flow) is estimated to be between about 4 and 12 years. Under steady-state conditions, groundwater flow from the pit could reach the Mofia River in about 32 years. Quasi-steady state conditions for the pit lake is estimated to be reached in somewhere between 20 and 60 years following the end of mining.

Table C2.10-9 presents an assessment of groundwater quality impacts based on the water quality modeling evaluation.

Impact Analysis

Table C2.10-10 presents a summary of the residual impacts with regard to groundwater quality.

The residual impacts on groundwater quality are negative for the Far North Aquifer and the North Aquifer. This is because of the potential for poor-quality seepage water (sulfate) to reach groundwater from the mine facilities, including the tailing storage facility and waste rock facilities. During operations, the Dipeta and South aquifers will not be affected by seepage from the mine facilities since any seepage that flows in a southerly direction will be captured by the pit dewatering system before reaching these aquifers. There is the potential to affect the Dipeta and South aquifers at post-closure via seepage from the pit lake.

Table C2.10-9 Mine Facilities and Their Potential Effect on Groundwater Quality

Facility	Area (ha)	Affected Subcatchment/Aquifer Unit	Effect on Groundwater Quality
water supply/ pit dewatering wells	-	Shimpidi, Kasana and Sokalwela/Far North Aquifer, North Aquifer/Dipeta Aquifer	no effect on groundwater quality impact = 0 (operations)
tailings storage facility	233	Kasana/Far North Aquifer	seepage from the tailings storage facility could affect local groundwater quality; small rate of seepage because of liner. impact = 0 to -1 (operations) 0 to -1 (post-closure)
return water pond[(a)]	20	Kasana/Far North Aquifer	seepage from the dam could affect local groundwater quality impact = 0 to -1 (operations) 0 (post-closure)
waste rock facilities	145	Kasana/Far North Aquifer	seepage from the waste rock facilities could affect local groundwater quality for nitrate and sulfate impact = -1 (operations) 0 to -1 (post-closure)
ore stockpile (east)	77	Kasana/Far North Aquifer	seepage from the ore stockpile facilities could affect local groundwater quality (arsenic and copper) impact = -1 (operations) 0 to -1 (post-closure)
ore stockpile (west)	38	Kasana/Far North Aquifer	seepage from the ore stockpile could affect local groundwater quality (arsenic and copper) impact = -1 (operations) 0 to -1 (post-closure)
run-of-mine pad	6	Kasana/Far North Aquifer	seepage from the facilities could affect local groundwater quality impact = -1 (operations) 0 to -1 (post-closure)
processing plant site	30	Shimpidi and Kasana/ Far North Aquifer and North Aquifer	potential effect on groundwater quality from spills impact = -1 (operations) 0 (post-closure)
pit lake (post-closure)	143	Shimpidi, Kasana and Sokalwela/Far North Aquifer, North Aquifer/Dipeta Aquifer	potential effect on groundwater quality (nitrate) impact = 0 to -1

[(a)] Estimated.
n/a = not applicable.
ha = hectares.

Table C2.10-10 Residual Impact Classification for GW-2

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question GW-2: What effect will the project have on groundwater quality?						
Far North Aquifer (tailings storage facility, waste rock facilities, processing plant, ore stockpiles, and pit lake)						
negative	low to moderate	local	long-term	no	high	low to moderate
North Aquifer (mine facilities include Kwatebala open pit and processing plant and pit lake)						
negative	low to moderate	local	long-term	no	high	low to moderate
Dipeta Aquifer (pit lake)						
negative	low to moderate	local	long-term	no	high	low to moderate
South Aquifer						
neutral	negligible	local	short-term	yes	low	negligible
Tshilongo Catchment						
neutral	none	none	none	-	-	negligible

The magnitude of the residual impacts to groundwater quality in the North Aquifer, Far North Aquifer and Dipeta Aquifer ranges from low to moderate. This is because of the range in the predicted seepage water quality and rates. The geographical extent of the impacts is assumed to be local, down-gradient of the facilities within the local watersheds.

The duration of the groundwater quality impacts is long term, corresponding to the life of the project and post-closure. Seepage will continue post-closure, contributing to a potential long-term groundwater quality impact. The impact is considered irreversible because seepage will continue post-closure from the tailings storage facility, the waste rock facilities and the pit lake.

The environmental consequence of the predicted effects is low to moderate depending on the hydrogeological conditions down-gradient of the waste rock facilities and low-grade ore stockpiles, tailings storage facility and pit lake.

Prediction Confidence

The impact predictions regarding groundwater quality are subject to some uncertainty because the hydrogeological conditions (groundwater travel times and flow paths) are drawn from the groundwater flow model which is sensitive to the interpreted geological conditions. The major source of uncertainty is associated with the characterization of the nature and horizontal and vertical extent of the low-permeability units at the mine site and their interaction with

surface water and springs. In the impact assessment this uncertainty is addressed by incorporating two different geological interpretations into the model and by presenting the results as a range rather than as a single-point estimate. This uncertainty will also be addressed through detailed operational monitoring of groundwater pumping rates, water table monitoring, and monitoring of groundwater quality and spring quality surrounding the mine site.

Monitoring

A groundwater quality monitoring program (Section D3.1.6) will be implemented during operations and closure to determine the impacts on groundwater quality caused by seepage from mine facilities and from the pit lake post closure. The monitoring program will include the following elements:

- Sampling and analysis of groundwater quality in monitoring wells up-gradient and down-gradient of mine facilities with the potential to impact groundwater quality. This monitoring will be augmented by recording groundwater levels to determine flow directions.
- Sampling and analysis of springs down-gradient of mine facilities.
- Sampling and analysis of the effluent (waste water) quality in the tailings storage facility.

C2.10.3.6 Key Question GW-3

Key question GW-3 is: How can the project have a long-term benefit on groundwater quantity and quality?

Linkage Analysis

Figure C2.10-1 shows the linkage between project activities and potential effects. Valid linkages exist for potential long-term benefits to groundwater quality and quantity in the RSA.

Assessment Methods

This assessment is carried out using professional judgment concerning the potential benefits of sustainable project mitigation measures, based on past experience with these techniques.

Mitigation

The preliminary analysis indicates that there is a potential for long-term reduction in groundwater recharge in the Kasana catchment because of the

tailings storage facility. This reduction in recharge may result in local declines in groundwater levels and possible loss of springs near the tailings storage facility area. To provide a sustainable groundwater supply for the local population who rely on springs, mitigation measures will include the construction of shallow wells completed with a mechanical hand-pump system. These systems will be able to provide a long-term sustainable groundwater supply for local villages.

A similar approach could be used to ensure the long-term sustainability of the groundwater supply for Fungurume. The wellfield would be handed over to the community with the establishment of a local water utility following provision of water system operator training. The wellfield would provide a long-term sustainable groundwater supply for the community. Fees levied by the utility for the use of water would provide for the upgrade and maintenance of the wells and infrastructure. Such a fee for service system may be difficult to implement in the concession. Furthermore, it may result in a disparity in access to water, with more affluent citizens being able to pay and others doing without.

The second element of a sustainable groundwater supply is water quality. Many local springs and shallow groundwater sources are contaminated by coliform bacteria. Education of the local population with regard to the protection and use of water from springs and dug wells will help improve public health.

Impact Analysis

The sustainability consequence of developing new groundwater supplies and public education are assessed separately. Both are critical components for the long-term sustainability of groundwater supply. Groundwater supply systems are of high importance in terms of magnitude, have the potential to affect both local rural/village and town populations, and have a long-term duration. Groundwater supply with hand pumps has had a high degree of success in similar settings. The probability of success is high and the long-term sustainability consequences are high (Table C2.10-11).

A fee for service groundwater utility, however, would be difficult to implement and may lead to a disparity in access to water. The probability of success is considered low.

Public education with respect to groundwater quality will potentially have a high effect. Public education will reach most or all of the community and will produce a long-term understanding of potential activities that can contaminate potable water supplies. The probability of success for this program is predicted to be medium, with a medium overall sustainability consequence (Table C2.10-11).

Table C2.10-11 Summary of Sustainability Assessment for Groundwater

Magnitude	Span or Reach	Duration	Probability of Success	Consequence
Key question GW-3: How can the project have a long-term benefit on groundwater quantity and quality?				
Groundwater supply systems				
high	a few people to entire community	long-term	high	high
Fee for service water utility				
high	a few people to entire community	long-term	low	medium
Public education				
high	a few people to entire community	long-term	medium	medium

Prediction Confidence

The prediction confidence for any one mitigation measure (i.e., effectiveness of developing local water systems, or a public education program concerning water quality) is low, as the success of each measure will depend on many factors outside of the TFM project's control. However, if implemented in combination with other kinds of education and research programs the probability of success of the sustainability measures will increase.

Monitoring

There will be no monitoring of water use from new water wells installed as part of mitigation for the loss of local village water supplies. Monitoring of groundwater quality post-closure will be according to the project monitoring plan.

C2.10.4 Cumulative Effects Assessment

Linkage Evaluation

Should the project be expanded from a production of 115,000 tonnes of copper per year to a 400,000 tonnes per year operation, the physical extent of waste rock facilities, ore stockpiles, tailings storage facility and other mine-related facilities would increase. In addition, it is likely that additional facilities would be constructed to accommodate the additional mining waste material. Expansion would require an increased groundwater supply for processing purposes. Pit dewatering requirements might also increase with larger and/or deeper pit(s). This linkage is valid.

A quantitative assessment of the Goma and Fwaulu pits was not undertaken for the ESIA. While a formal assessment of impacts to groundwater from development of these pits will be completed before they are mined, a qualitative assessment is provided in this section.

Assessment Methods

Detailed plans for the additional development of the TFM project to expand to 400,000 tonnes of copper production per year are not yet available. However, such a development would include additional mines within the Fungurume ore body and an additional processing plant and tailings storage facility (Section A4.17). These effects were reviewed in the context of known baseline conditions for groundwater and based on professional experience. Professional experience in relation to the changes in groundwater caused by mining, processing, tailings and waste rock facilities, and an increased local population was used to develop an understanding of the potential effect of an expanded project. Principles developed for closure plans and other project goals for long-term mitigation of effects were used to develop an assessment of long-term impacts.

Mitigation

The mitigation presented above for key questions GW-1 and GW-2 will be implemented on a larger scale to address the effects of the Goma and Fwaulu pits as well as an expanded 400,000 tonnes per year project. At the time of the decision to expand the project, an additional assessment of groundwater quantity and quality would be completed to determine if additional supplementary mitigation is needed.

Impact Analysis

Development of the Goma and Fwaulu pits as well as an expanded project would have similar impacts on groundwater resources and groundwater quality compared to the proposed project (see Figure C2.10-1). A possible exception is that some of the ore and waste materials mined in the future (for the expanded project)may have significant sulfide contents, leading to the potential for acid generation when exposed to the atmosphere. Operations covered under the current mine plans are very low in sulfides and do not have a significant acid generation potential. The Goma and Fwaulu ore bodies are also believed to be low in sulfides but this will be confirmed prior to mining. The larger footprint for mine facilities and greater water demand (for process and dewatering), would have greater impacts on groundwater levels, groundwater discharge to springs and streams and groundwater quality. Loss of groundwater recharge would be greater because of an additional tailings storage facility. Additional use of

groundwater for processing would result in lower groundwater levels around the water supply wells. If additional dewatering is required for a larger, deeper pit then impacts could exceed those predicted for the 115,000 tonnes per year project.

Given the limited information on the expanded project and limited information on the site hydrogeology available for this ESIA, no additional analysis of impacts is presented here. A qualitative assessment indicates that effects to groundwater could have a moderate to high environmental consequence for both the Goma and Fwaulu pits as well as the 400,000 tonnes per year case (Table C2.10-12). This is due to an expectation of moderate to high changes in groundwater levels, the regional nature of the changes (pits will be developed across multiple catchments), and the long-term duration (life-of-mine) of the changes. This is a conservative assessment that will be re-assessed prior to development.

Table C2.10-12 Summary of Residual Cumulative Impact Classification for Groundwater

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question $GW_{(ce)}$-1: What effect will the expanded project have on groundwater quantity and quality?						
Existing developments + KwatebsIsKwatebala + Goma + Fwaulu						
negative	moderate to high	local	long-term	reversible for groundwater quantity Irreversible for groundwater quality	high	moderate to high
negative	moderate to high	local	long-term	reversible for groundwater quantity irreversible for groundwater quality	high	moderate to high
Existing developments + the TFM Project + future expansion (400,000 t/a)						
negative	moderate to high	local for groundwater quality local to potentially regional (depending on water use and pit lake conditions) for groundwater quantity	long-term	reversible for groundwater quantity irreversible for groundwater quality	high	moderate to high

t/a = tonnes per annum (year).

ce = cumulative effects.

Prediction Confidence

Information concerning the effects of development of Goma and Fwaulu, and a larger 400,000 tonnes per year project is limited but a general understanding of the effects of such projects is in place. The assessment results presented in

Table C2.10-12 are conservative. The prediction confidence for this assessment is moderate. If the larger project goes ahead, a new assessment will be prepared prior to development of either scenario.

Monitoring

Monitoring efforts under the cumulative case will be similar to that proposed for key questions GW-1 through GW-3, but larger in scale. If these projects go ahead, more detailed monitoring information will be prepared.

C2.10.5 Conclusions

The residual impacts on the groundwater system from the planned mining operation are summarized in Table C2.10-13.

Groundwater Quality

Construction activities will modify runoff and infiltration conditions in disturbed areas. Groundwater recharge will be reduced in the area of the tailings storage facility because of the placement of a low-permeability liner. Groundwater recharge may also decrease in the processing plant site area due to compaction of soils and capture and use of storm water runoff.

Construction of the waste rock facilities and ore stockpiles may have little effect on groundwater recharge during mine operations because precipitation will enter the stockpiles, seep to the ground surface and infiltrate to groundwater. At closure, the top surface of the waste rock facilities will be covered with soil and re-vegetated to limit infiltration and reduce groundwater recharge.

The mine water supply/mine dewatering operations will result in a decreased availability of groundwater resources that will be reflected in lowered groundwater levels around the open mine pit. The lowered groundwater levels may reduce groundwater discharge to springs and to surface water (baseflow) near the mine.

The groundwater resources impacts will be greatest in the Far North and North Aquifers since these underlie the open pit area and mine facilities. Lesser impacts are expected within the Dipeta Aquifer and South Aquifers. The magnitude of the impacts to groundwater resources is considered moderate to high, dependent on the hydrogeological conditions and change in recharge to pre-existing groundwater recharge conditions.

Impacts to groundwater resources are considered long-term (life of mine). Impacts to the water supply/dewatering system are reversible once a pit lake has established a new hydrologic equilibrium. The overall environmental effects are considered low to moderate depending on the hydrogeological conditions.

Table C2.10-13 Residual Impact Classification for Groundwater

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question GW-1: What effect will the project have on the groundwater resources including groundwater levels, groundwater availability and groundwater discharge to springs and surface water (baseflow)?						
Far North Aquifer (tailings storage facility, waste rock facilities, processing plant site, ore stockpiles)						
negative	moderate to high	local to regional	long-term	yes	high	moderate to high
North Aquifer (Kwatebala open pit mine, processing plant)						
negative	moderate to high	local to regional	long-term	yes	high	moderate to high
Dipeta Aquifer (no mine facilities)						
negative / neutral	negligible to low	local	medium-term	yes	low	negligible to low
South Aquifer (no mine facilities)						
negative / neutral	negligible to low	local	medium-term	yes	low	negligible to low
Tshilongo Catchment (no mine facilities)						
negative / neutral	negligible to low	local	medium-term	yes	low	negligible to low
Key question GW-2: What effect will the project have on groundwater quality?						
Far North Aquifer (tailings storage facility, waste rock facilities, processing plant site, ore stockpiles)						
negative	low to moderate	local	long-term	no	high	low to moderate
North Aquifer (mine facilities include Kwatebala open pit and processing plant)						
negative	low to moderate	local	long-term	no	high	low to moderate
Dipeta Aquifer (pit lake)						
negative	low to moderate	local	long-term	no	high	low to moderate
South Aquifer						
neutral	negligible	local	short-term	yes	low	negligible
Tshilongo Catchment						
neutral	none	none	none	-	-	negligible

Groundwater Quality

Seepage from the mine infrastructure such as the tailings storage facility, waste rock facility, ore stockpiles, pollution control dams is predicted to negatively impact local groundwater quality for sulfate and nitrate only, down-gradient of these facilities. Sulfate has a secondary drinking water standard for aesthetic rather than health-based concerns. All other constituents will be either lower than EPA drinking water standards in the seepage water or will be significantly attenuated in their passage through the soil and aquifer matrix resulting in concentrations lower than EPA drinking water standards. Accidental chemical

spills at the plant site, that are not within the paved surfaces and collected by internal drainage system, may also negatively impact groundwater quality.

During mine operations and closure, the greatest potential for groundwater quality impacts is for the Far North and North Aquifers. This is because the tailings storage facility, waste rock facilities, and pollution control dams are located overlying these aquifers. Seepage from these facilities may locally affect groundwater quality down-gradient of these facilities. During operations, the Dipeta and South aquifers will not be affected by seepage from the mine facilities since any seepage that flows in a southerly direction will be captured by the pit dewatering system before reaching these aquifers. There is the potential to affect the Dipeta and South Aquifers at post-closure via seepage from the pit lake.

Groundwater quality impacts are considered long term and not reversible. Continued post-closure seepage from the tailings storage facility, waste rock facilities and pit lake will contribute to long-term groundwater quality impacts. Reclamation of the processing plant area and other mine facilities will result in long-term reversible impacts to groundwater quality. The overall environmental consequence is considered low to moderate because of the limited seepage expected from the reclaimed facilities.

Sustainability

Table C2.10-14 presents a summary of the sustainability assessment for groundwater. Sustainability elements in the project will include development of large and small groundwater supply systems and public education for water quality.

Table C2.10-14 Summary of Sustainability Assessment for Groundwater

Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key question GW-3: How can the project have a long-term benefit on groundwater quantity and quality?				
Groundwater supply systems				
high	a few people to entire community	long-term	high	high
Public education				
high	a few people to entire community	long-term	medium	moderate

Cumulative Effects

The cumulative effects of a larger mining project (the expanded project) will be negative since a larger area will be influenced, more water will be required for processing and dewatering, and more waste rock, tailings and ore will be stockpiled. With combined impacts on groundwater, a moderate to high environmental consequence is expected (Table C2.10-15).

Table C2.10-15 Summary of Residual Cumulative Impact Classification for Groundwater

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question $GW_{(ce)}$-1: What effect will the expanded project have on groundwater quantity and quality?						
Existing developments + the TFM project + future expansion (400,000 t/y)						
negative	high	local for groundwater quality local to regional for groundwater quantity	long-term	reversible for groundwater quantity irreversible for groundwater quality	high	moderate to high

t/y = tonnes per year.

C2.11 SURFACE WATER HYDROLOGY

C2.11.1 Introduction

This section presents the environmental assessment for the effects of the Tenke Fungurume Mining (TFM) project on river flows, river geomorphology and surface water supply. The information presented meets the project's terms of reference (Appendix E8) and includes details on:

- Water supply concerns identified by stakeholders and regulators.
- Components within each phase of the project that may influence or affect flows in the rivers.
- Proposed mitigation measures to be considered, during the construction, operation and reclamation phases of the project, to maintain the existing flow regime as far as possible.
- Impact assessment (using qualitative and quantitative methods) for potential impacts of the project on river flows which could affect channel morphology (form and structure) and water supply.
- Sustainability assessment for key issues relating to river flows.
- The monitoring program that will be used to identify and monitor project impacts on flows in the rivers.

This section of the environmental and social impact assessment (ESIA) is organized as follows:

- Section C2.11.2 describes the study areas.
- Section C2.11.3 discusses the impact assessment approach and results.
- Section C2.11.4 provides the cumulative effects assessment.
- Section C2.11.5 discusses the conclusions of the assessment.

Regional climate and hydrologic information has been compiled to characterize baseline conditions in the study area (Section B2.11).

A glossary of terms and acronyms used in this section is provided at the back of this volume.

C2.11.2 STUDY AREAS

Figures of the study areas used for the hydrological assessment are provided in Section C1.1. The Regional Study Area (RSA) covers the Mofia and the Dipeta river catchments and a small portion of the Tshilongo River catchment near Tenke. Proposed and potential future mining activities in the TFM project concession will occur within these areas (Figure C1.5-1).

The area where mining and its associated activities have the potential to directly affect surface water comprises the Local Study Area (LSA) (Figure C1.5-1). The mine is located in the upper Dipeta, Shimpidi, Sokalwela and Kasana river catchments. The airstrip, limestone quarry and construction camp/permanent village will be located in the Kabomboy River catchment. Changes in these subcatchments also have the potential to affect flows in the Dipeta and Mofia rivers. Construction and operation of access roads have the potential to cause localized effects in a number of other tributary catchments of the Mofia and Dipeta rivers.

The surface water hydrology assessment covers the Mofia River and the Dipeta River catchments, upstream of the airstrip and Fungurume respectively. These two catchments were selected since potential flow changes resulting from mining operations at Kwatebala Hill (the focus of the assessment) will be limited to these two river systems. The mining activity generally straddles the watershed of the two catchments. In the future, the Goma and Fwaulu hills will also be mined, which may affect flows in the Tshilongo River catchment. This catchment has also been included in the RSA, but with a less rigorous assessment.

The Dipeta River flows generally from west to east and drains the southern regions of the TFM concession area.

C2.11.3 Impact Assessment

C2.11.3.1 Issue Scoping

Development of the TFM project will involve varying degrees of land disturbance, such as removal of vegetation, excavation and ground compaction. The project will also include the construction of roads, buildings, parking and storage areas, waste rock facilities and other facilities. These disturbances will result in increased runoff from the site until reclamation activities and revegetation activities are complete. However, not all runoff from the development will be released to the environment. Storm water and storm water-derived toe seepage from process areas or areas impacted by process

materials, ore and waste rock ("contact" water) will typically be collected and used in the process water circuit. This water will be lost from the downgradient surface waters.

The development of the tailings storage facility and various waste rock facilities and ore stockpiles will involve the collection and diversion of surface runoff in the upper basins of the catchments. All waters not meeting applicable water quality standards for release to surface waters, or that may impair established downstream uses of that water, will be captured and integrated into the process water circuit. As a result of these diversions and the capture of this contact storm water, flows in the downstream valleys will be reduced and the availability of water for other users (i.e., human and animal consumption, irrigation and fish habitat) may be affected. Releases (effluent) from a sewage treatment works associated with the project will release water into a river, increasing the flows in that river. Long-term changes in flows could affect the channel morphology of receiving streams.

The project has the potential to affect surface water flows as a result of a number of activities, including:

- Diversion and disruptions of natural drainage lines.
- Groundwater dewatering and subsequent decrease in surface water flows.
- Discharge of treated sewage effluent (wastewater).
- Accidental releases and spills.
- Bunding of areas to contain contaminated storm water.
- Site reclamation and closure activities.

A number of concerns relating to potential changes in the availability and quality of surface water were noted during the public consultation process (Section A6). These include:

- The interruption of flows and potential impacts on the continued use and availability of well water by communities for domestic use, for livestock and for irrigation.
- Concern regarding changes to stream flows in the streams surrounding the mine and consequent effects on the surface water supply for local communities.

The disruption to flows may have an affect on the geomorphology of the river channels. Significant increases in flows will result in additional erosion of the channels. Significant reduction in flows will result in the streams and rivers depositing the sediment load that they carry, resulting in silting up the river channels.

Future mining operations at Goma may require the upper Dipeta River to be diverted. This may or may not require an attenuation dam. If no attenuation dam is used, losses as a result of the diversion may be small. The Dipeta River is a gaining river (being fed from groundwater). Significant seepage losses through the Dipeta River's diverted channel are not expected unless this channel is significantly higher than the original channel. However, some dry season seepage into the surrounding ground may occur. An attenuation dam may be used to reduce flood peaks that the diversion channel would be required to carry. This will have higher losses associated with it due to evaporation and seepage from the dam. The magnitude of these losses will depend on the size of the attenuation dam and its designed attenuation time. This impact will be assessed prior to development of the Goma pit in an addendum to this ESIA or a separate ESIA

C2.11.3.2 Key Questions and Indicators

The linkages shown in Figure C2.11-1 were assessed by answering key questions for surface water hydrology (Table C2.11-1). The use of linkage analysis and key questions is described in Section A5. Key questions are related to stream flow, channel geomorphology and water supply.

Table C2.11-1 Key Questions for Surface Water Hydrology

Impact Assessment	
Key question SWH-1:	What effect will the project have on stream flow in the local watercourses?
Key question SWH-2:	What effect will altered stream flow have on channel geomorphology?
Key question SWH-3:	What effect will altered stream flow have on water supply?

Sustainability benefits relating to stream flow are not really possible. Provided adequate rehabilitation takes place, stream flow will almost be returned to baseline conditions. Attempts to enhance runoff would involve land use change and possible channel geomorphological change. As a result, no sustainability assessment was conducted.

Water supply during the life of mine will be obtained from groundwater. Sustainability regarding water supply is discussed in the groundwater impact assessment (Section C2.10).

A dam may be constructed as part of a river diversion at Goma. This dam may be used to enhance water supply in Tenke and its immediate surroundings. This will depend on the type of dam that is constructed. If the dam is merely an attenuation dam to reduce flood peaks, it will store no water in the long term, and will be of little benefit for water supply. If the dam is designed to store water it may benefit water storage needs. This dam will come with environmental consequences such as reduced flow and temperature changes. These aspects will need to be considered in more detail prior to mining of Goma and construction of any required water handling structures.

Indicators for the surface water hydrology impact assessment include those presented in Table C2.11-2. Indicators for the ESIA include seasonal (wet and dry season) stream flows in affected streams, changes in channel geomorphology and seasonal water supply at nearby villages or other receptors (assessment nodes).

Table C2.11-2 Indicators for Surface Water Hydrology

GRI[a]		FIDIC[b]		ESIA
EN13	measurements of water usage by project during all phases	EN5	total water use	seasonal stream flow at assessment nodes
	n/a		n/a	changes to channel geomorphology
	n/a		n/a	seasonal water supply at assessment nodes

[a] Global Reporting Initiative (GRI 2005).

[b] International Federation of Consulting Engineers (FIDIC 2004).

n/a = Not applicable.

C2.11.3.3 Assessment Criteria

Surface water hydrology impacts result in a change in flow. The impact of a change in flow cannot be assessed in itself. It can only be assessed when the change in flow has a consequential benefit or disadvantage to a receptor. Most receptors that may be impacted by flow changes in the rivers are dealt with in other disciplines. These include receptors such as flora (Section C3.1), fauna (Section C3.2) fish and aquatic habitat (Section C3.3) and humans (socio-economics, in Section C4.1). The impacts of flow changes on these receptors are described in their respective impact studies. The surface water quality impact assessment provides information on changes in surface water quality (Section C2.12). This surface water hydrology impact assessment provides information on changes in flows (key questions SWH-1) and water supply (SWH-3). The studies for water quality, flora, fauna, fish and aquatic habitat and socio-economics use these key questions to conduct their impact assessments.

Changes in flows can result in changes in channel geomorphology (SWH-2). Effects on channel morphology are described and quantified in this hydrology assessment. The assessment criteria used for effects on channel morphology are presented in Table C2.11-3.

Table C2.11-3 Impact Description Criteria for Surface Water Hydrology

Resource	Direction[a]	Magnitude[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
surface water hydrology	**increase, decrease** or **neutral** for the river flows	**negligible:** <20% change **low**: 20 to 30% change **moderate**: 30 to 40% change **high**: >40% 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**: <2 years **medium-term**: 2 to 20 years **long-term**: >20 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: increase or decrease effect for measurement endpoints, as defined for specific component.

(b) Magnitude: degree of change to analysis endpoint – based on channel morphology impacts.

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

(d) Duration: length of time over which the environment effect occurs. Considers a two-year construction period and a 20-year operation period.

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

(f) Frequency: how often the environmental effect occurs.

C2.11.3.4 Key Question SWH-1

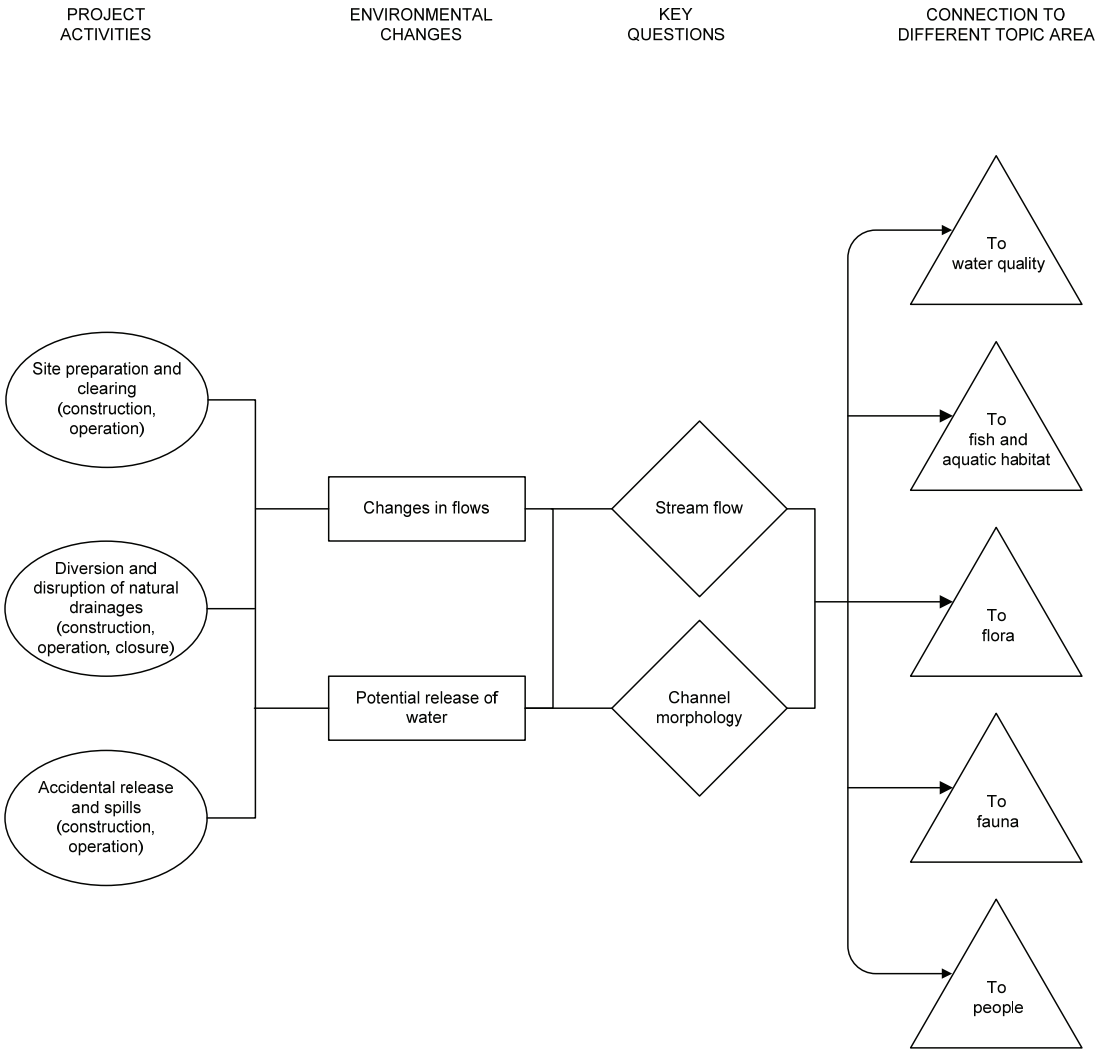
Key question SWH-1 is: What effect will the project have on stream flow in the local watercourses?

Linkage Evaluation

The linkages between project activities and potential effects on river flows are shown in Figure C2.11-1. Potential river flow changes could occur during all phases of the project. The key questions used to guide this assessment are also shown. Results of this assessment, that were used in other components of the ESIA, are shown to the right.

The linkages associated with key question SWH-1 are described in this section. Project activities during construction, operation and closure may result in changes in flows to receiving waterbodies. During the operation phase, water of both good and poor quality may be released into the receiving environment. The linkages are valid.

Figure C2.11-1 Surface Water Hydrology Linkage Diagram



Project Activities that May Affect Stream Flow

Runoff from the natural catchments is typically low, ranging between 10 and 20 percent of the mean annual rainfall. This means that only 10 to 20 percent of rainfall ends up as flow in the rivers. Infiltration is high in the natural catchments and a significant portion of this water will reach the streams via the shallow (interflow) and deep groundwater (springs) system as opposed to overland flow. The high infiltration is mostly caused by the deep, well-drained soils. The rest of the rainfall infiltrates to groundwater or is lost to the atmosphere through evaporation and transpiration. The development of the mine will involve some clearing of vegetation, surface compaction and the construction of infrastructure. All of these developments will result in increased runoff. For example, runoff from paved areas is often over 60 percent of the mean annual rainfall.

Tailings Storage Facility

Development of the tailings storage facility will involve three operational phases in which tailings are deposited in a progressively larger tailings basin. The tailings storage facility will intercept rainfall, which will be redirected into the process water circuit via a dedicated return water dam. Rainfall falling on the entire footprint of the tailings storage facility will be intercepted and will not contribute to downgradient surface water flow. The operation phase will be followed by a closure phase, in which the tailings storage facility will be reshaped, to a limited degree, and rehabilitated. The reshaping will ensure free drainage via a spillway designed to accommodate a one in 10,000-year discharge.

Return Water Dam

The return water dam will serve as a buffer dam between the tailings storage facility and the processing plant. Supernatant water on the tailings storage facility will accumulate in a pool as a result of floor beaching and deposition control. This supernatant water, mostly derived from the process, but also from rainfall, must be decanted (drawn off) from the surface of the tailings storage facility for the following reasons:

- To conserve water.
- To prevent accumulation and eventually overtopping.
- To allow drying and consolidation of the tailings slurry.

A large pump system (barge pump arrangement) has been designed to pump supernatant water from the tailings storage facility. This water is discharged into the return water dam for reuse in the plant. Rainfall falling on the tailings storage facility and return water dam will be included in the process water circuit. This water will no longer contribute to runoff and recharge in the catchment.

Areas Designated as Contact Areas

Certain areas of the processing plant and its related infrastructure are designated as contact areas. Contaminated storm water from these areas will be separated from uncontaminated (non-contact) storm water, and directed to the process water circuit. Rainfall falling on these areas will not contribute to runoff from the catchment. These areas include the processing plant, run-of-mine pad, waste rock facilities and low-grade ore stockpiles.

Mine Pit

During the about the first seven years the pit will be above the groundwater level. Dewatering of the open pit will not be required until about Year 8 of operation. To maintain dry conditions within the pit, the water table in the vicinity of the mine will be lowered to the level of the bottom of the pit. (Section C2.10). Any local springs within the "cone of depression" of this dewatering program will dry up. The cone of depression is the area within which the water table is lowered.

For the purpose of this impact assessment, it is assumed that rainfall falling within the mine pit perimeter will be lost from natural runoff processes. The conservative assumption is being made that all water in the mine pit will be considered as contact water and pumped into the process water system, to be used in the processing plant. In fact, this may not be the case, as some of the water will probably meet applicable standards for release to downgradient surface waters. Under the assumption that all rainfall must be captured, the loss of surface storm water runoff to receiving streams will increase as the pit perimeter increases. This loss of natural runoff will affect both groundwater and surface water.

Without the pit, rainfall would have infiltrated and recharged the groundwater. This loss in recharge will be proportional to the area of the pit. This loss in recharge will affect baseflow in the streams in the vicinity of the pit, as baseflow is mostly fed from deeper groundwater. The reduction in baseflow is expected to be limited. Surface runoff (quick flow) generated from the headwaters of the local catchments is low. Similarly, rainfall falling within the pit perimeter that would have generated surface runoff will no longer generate surface runoff. This reduction in surface runoff is assumed to be proportional to the pit area.

Assessment Methods

Overall Assessment Methods

This assessment assumes that mitigation is in place for the project and is reflected in the assessment results. The approach for quantifying the changes in surface water conditions and assessing the effects is described below:

- Identify the main receiving watercourses and waterbodies to be affected by the project.
- Select the locations (assessment nodes) of the affected watercourses where changes will be quantified.
- Examine the schedule of mining and water management activities and select representative assessment periods or time snapshots for analyzing the changes.
- Select key surface water quantity parameters for characterizing the natural variability of surface water quantity conditions.
- Quantify the changes in surface water quantity parameters using models and other analytical techniques.
- Account for the mitigation measures and design features to reduce the project's effects on surface water quantity.
- Compare the predicted changes with baseline and pre-development conditions to quantify the incremental and cumulative effects.
- Define the potential surface water quantity monitoring programs to monitor the effectiveness of the proposed design features and mitigation measures.

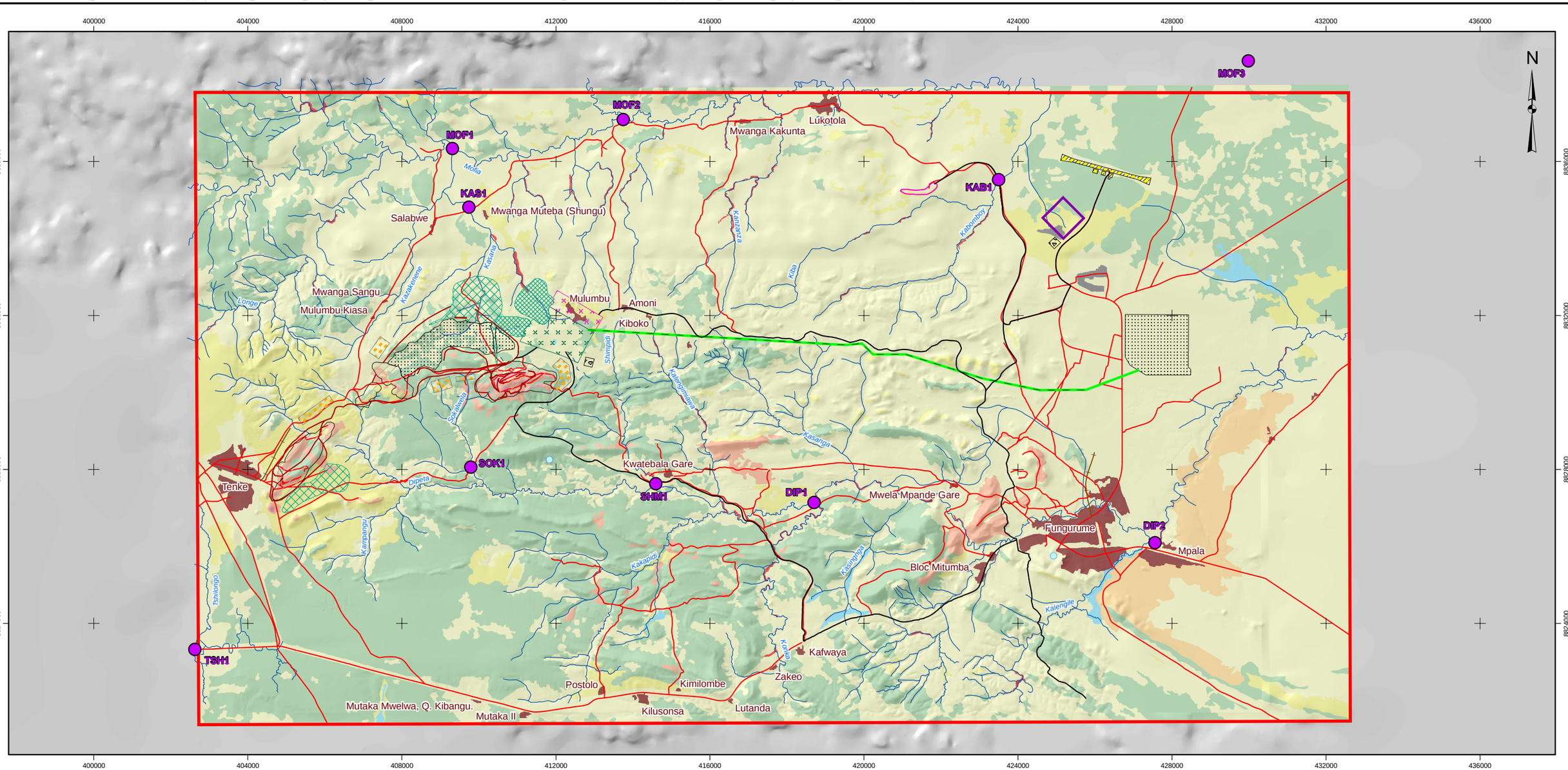
Assessment Nodes

The location of assessment nodes is impact driven. This means that, where flow changes are likely to cause environmental impacts, flow changes were assessed. Key drivers of this process were the fish and aquatic habitat (Section C3.3), flora (Section C3.1) and socio-economic (Section C4.1) assessments.

Table C2.11-4 lists the assessment nodes defined for this study, their locations and the rationale for site selection. Figure C2.11-2 shows these nodes.

Table C2.11-4 Impact Assessment Nodes

Node	Location	Rationale
KAS1	at the flow monitoring point on the Kasana River	Flows in the Kasana River will be altered by the mining operation. This location on the river usually has flow as springs that feed this river are upstream of this node. This node is located adjacent to Mwanga Muteba Village, where washing and ablution activities may occur. Drinking water is usually taken from the springs at source as well as the river itself. As a result, water quality impacts are also important here.
MOF1	on the Mofia River, just downstream of the confluence with the Kasana River, corresponds to the upper Mofia flow monitoring point	The flow changes on the Mofia River, as a result of flow changes in the Kasana River, will be most acute just downstream of the confluence of these two rivers.
MOF2	a few kilometers downstream of MOF1, corresponds to the mid - Mofia flow monitoring point	The effects on flows in the Mofia River, as a result of flow changes in the Kasana River, will be diluted once the Mofia receives flow from a major tributary from the north and a few kilometers downstream of MOF1. The reduced flow changes can be assessed at this node.
KAB1	on the Kabomboy River where the northern access road crosses the Kabomboy River	The sewage treatment plant will discharge treated effluent into the Kabomboy River, upstream of where the Kabomboy River crosses under the Mulumbu access road.
DIP1	on the Dipeta River, just upstream of the confluence with the Konka River, corresponding to the mid - Dipeta flow monitoring point	The effects of the project on the Dipeta River will be most noticeable downstream of the Shimpidi River and upstream of the Konka River.
DIP2	on the Dipeta River downstream of Fungurume, corresponds to the lower Dipeta flow monitoring point	Any affects by the Fungurume community on the Dipeta River will be able to be assessed just downstream of Fungurume. It will also provide a site beyond which the project has no further affect on flow in the Dipeta River.
MOF3	on the Mofia River, downstream of the confluence with the Kabomboy River, corresponds to the lower Mofia flow monitoring point	This will provide a site beyond which the project has no further effect on flow in the Mofia River.
SOK1	on the Sokalwela River, at the road crossing between Mwanga and Salabwe villages	There are gallery forests in the region of this monitoring point. This will provide an indication of the anticipated flow changes in the vicinity of these forests.
SHM1	on the Shimpidi River, where it crosses under the railway line	There are gallery forests and good fish habitat in the region of this monitoring point. This will provide an indication of the anticipated flow changes in the vicinity of these resources.
TSH1	on the Tshilongo River where the Kolwezi-Fungurume road crosses the Tshilongo River	This location will be immediately downstream of mining activities at Goma.



LÉGENDE / LEGEND

- NOEUD D'ÉVALUATION / ASSESSMENT NODE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- ZONE D'ÉTUDE RÉGIONALE / REGIONAL STUDY AREA

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE

- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

COUVERTURE VÉGÉTALE / UTILISATION DU TERRAIN / LANDCOVER

- AFFLEUREMENT ROCHEUX DE MINERAI CUIVRE-COBALT - COMPLEXE EXPLOITÉ PAR L'ACTIVITÉ MINIÈRE ARTISANALE / COPPER-COBALT ROCK OUTCROP - ARTISANAL MINING COMPLEX
- STEPPE-SAVANE SUR SUBSTRAT CUPRO-COBALTIFÈRE / COPPER-COBALT STEPPE-SAVANNA
- FORÊT DE MIOMBO / MIOMBO WOODLAND
- FORÊT DE MIOMBO DÉGRADÉE / MIOMBO WOODLAND DEGRADED
- FORÊT GALERIE / GALLERY FOREST
- ZONE HUMIDE / WETLAND
- MOSAÏQUE AGRICOLE / AGRICULTURAL MOSAIC
- ANCIENNE JACHÈRE / OLD FALLOW FIELD
- AÉROPORT / AIRFIELD
- PERTURBATION / DISTURBANCE
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

ÉCHELLE / SCALE		KILOMÈTRES / KILOMETERS
1:100000	3 0 3	
1:100000		

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

NOEUD D'ÉVALUATION POUR L'ÉTUDE HYDROLOGIQUE / ASSESSMENT NODES FOR SURFACE WATER HYDROLOGY

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	BR	03 Apr. 2006		
GIS / SIG	KL	04 Jan. 2007		
VÉRIFIÉ / CHECK	MR	01 Nov. 2006		
APPROUVÉ / REVIEW	MR	01 Nov. 2006		

FIGURE: C2.11-2

Modeling Assumptions

Assumptions for hydrologic modeling are based on the current project design. The environmental team worked closely with the engineering design team to develop reasonable assumptions with sufficient detail to enable water balance simulation. Some aspects of engineering may change as a result of future detailed engineering. As a result, some specific assumptions may also change. Mitigation measures will ensure that any effects on flows and water levels will be within the levels presented in this assessment.

The following mine facilities will divert water to the process water circuit during operation:

- Tailings storage facility.
- Open pit.
- Waste rock facilities.
- Long-term ore stockpiles (east and west).
- Processing plant areas.
- Return water dam.
- Run-of-mine pad.

Effects on flows from the construction camp sewage treatment plant releases were calculated using typical water requirements per worker.

Temporal Considerations

The effects of the project on flows were evaluated at two snapshots in time: Year 7 (before dewatering) and Year 15 (during dewatering). These assessment snapshots were selected based on information in the mine and water management plans and capture the project's effects during the mine's life. The rationale for selecting these snapshots is provided in Table C2.11-5.

Table C2.11-5 Snapshots for Quantifying Changes in Flows

Period	Rationale
Year 7	this is a snapshot before start of pit dewatering and bottom of the pit is above the groundwater table
Year 15	this is the snapshot after pit dewatering is initiated and project facilities are at their maximum extent

Assessment Methodologies

Changes in flows in receiving streams were evaluated based on predicted changes in estimated surface water and groundwater contributions at various locations downstream of the project. Baseline runoff characteristics were derived from field observations in 2005 and 2006 and runoff modeling. These were used to estimate pre-development surface water and groundwater contributions to stream flow.

Groundwater contributions play a significant role in stream flow, particularly during the dry season. The smaller tributaries behave differently to the larger rivers in terms of storm flow and baseflow. As a result, changes were separated into the following three components:

- Effects on storm flow (high flows).
- Effects on baseflow.
- Effects on total runoff.

Effects on Storm Flow

Effects on storm flow will be dominated by the change in area of project facilities, and land use of the areas contributing to the flow in the rivers. Changes in storm flow (surface runoff) during operations were estimated by considering the reduced drainage areas resulting from runoff diversion in the upper basins. For example, a five percent reduction in area contributing to runoff will result in a five percent reduction in storm flow.

Effects on Baseflow

Effects on baseflow will be dominated by the changes in groundwater contributions to the rivers, mostly through spring flow. The effect of mine dewatering on the spring flows in the tributaries is critical in determining these effects.

The detailed groundwater modeling (Appendix C2.10-I) showed that pit dewatering impacts on the Mofia catchment will be minimal and will amount to less than 30 liters per second or 0.9 percent of the average baseflow in the Mofia River. We can assume that the tributaries feeding the Mofia River will be affected and the total baseflow in these tributaries will be reduced by about 30 liters per second. This impact will largely be split between the Kasana and the Kanzekanene Rivers, and the tributaries to the north of Mulumbu village. The greatest impact will be on the Kasana River. This is evident by looking at the aerial extent of the simulated drawdown cone. The cone's greatest impacts in the Mofia catchment occur in the Kasana River catchment. We therefore expect that

the baseflow in the Kasana River at assessment node KAS1 will be in the order of 15 liters per second and therefore may dry up.

Dewatering impacts on the baseflow in the Dipeta River catchment are greater than the impacts on the Mofia River. The groundwater modeling showed that baseflow in the Dipeta River will be reduced by 90 liters per second to 460 liters per second or by 3.2 percent to 16.4 percent of the Dipeta River baseflow. These impacts will mainly occur in the Sokalwela, Shimpidi, Kalengimiawa and the Dipeta rivers. This is evident from the extent of the drawdown cone. Baseflow in the Sokalwela and Shimpidi Rivers is likely to be affected. It is likely that the Sokalwela River may dry up as a result of the dewatering activity, and flows in the Shimpidi River will be reduced by as much as 75 percent. Baseflow contributions directly to the Dipeta River are also likely to be affected.

Effects on Total Runoff

The effects on total runoff are the sum of the storm flow and baseflow effects. Average wet and dry season flows are used in the assessment. These flows are provided in the surface water hydrology baseline (Section B2.11).

Effects on Flows in Tributaries

Flow changes in the Sokalwela, Kasana and Shimpidi rivers were calculated in a three-step approach:

1. The proportions of storm flow and spring flow (including interflow) that make up the total flow in the rivers were calculated. This was done for both the wet and dry seasons. The lowest recorded flow during the wet season was assumed to be the spring flow. All flows above this flow were considered to be storm flow. During the dry season, there is no rain so all flow is a result of spring flow.
2. Spring flow was reduced by the modeled reduction in spring flow. The storm flow component was reduced by the amount of catchment that no longer contributes to flow from the catchment.
3. The two reductions were then added together to get the total reduction in flow in the Sokalwela, Kasana and Shimpidi rivers.

Prior to dewatering, the spring flow reductions were calculated by the proportion of non-contributing (recharge) areas to the area of the aquifer above the spring elevation. The springs that feed the Kasana River are part of the Far North Aquifer (hydrogeology baseline Section B2.10). The boundaries of this aquifer are not known, but the western and eastern boundaries are assumed to be in the vicinity of Tenke and Mulumbu villages, respectively. The northern boundary is defined by the spring elevations. The southern boundary is assumed to be in the

vicinity of the Shanika Kundelungu Fragment. Springs that feed the Sokalwela and Shimpidi rivers are assumed to be in a separate compartment – possibly the Shanika Kundelungu Fragment. The pit and a portion of the plant area are the only infrastructure in this compartment. It has been assumed that these will not significantly change recharge to the groundwater.

Effects on Flow in the Mofia and Dipeta Rivers

Flow changes on the Mofia River were calculated by multiplying the effect on total flow of the Kasana River by the relative contribution of the Kasana River flow to the Mofia River flow at each assessment node on the Mofia River. Flow changes on the Dipeta River were calculated by multiplying the effect on total flow of the Sokalwela and Shimpidi rivers by the relative contribution of these rivers to the Dipeta River flow at each assessment node on the Dipeta River. The simulated direct impacts of dewatering on the Dipeta River were also accounted for.

Effects on Flows in the Kabomboy River

Flow changes on the Kabomboy River were calculated using the upper and lower estimate of releases from the construction camp/permanent village sewage treatment plant. The released flows are based on the following assumptions:

- 2,500 people being serviced by the sewage treatment plant at the camp.
- Upper estimate flow – 200 liters per person per day (Section C2.12).
- Lower estimate flow – 80 liters per person per day (Section C2.12).

The water requirement estimates are for mining camps and include water for drinking and hygiene. Some water for gardening is included in the upper estimate of water use, even though this water would not end up in the sewage treatment plant. Therefore, the upper estimate is a conservative estimate of released flows. The released flows were then assessed in terms of flows expected in the Kabomboy River. Flows in the Kabomboy River were not measured or simulated. Based on the land use and topography of the catchment, it was assumed that flows in the Kabomboy River would resemble those in the upper Dipeta River. The unit flows simulated using Agriculture Catchments Research Unit (ACRU) (Table B2.11-3) were used to calculate average wet and dry season flows in the Kabomboy River. The 95th percentile wet season simulated flows in the upper Dipeta River were used to calculate storm flows in the Kabomboy River. These storm flows were then used to assess the flow changes as a result of the sewage treatment plant releases on the Kabomboy River. The assessment was made by calculating the incremental increase in flow as a result of these releases.

The 95th percentile wet season simulated flows for the upper Dipeta River are shown in Table C2.11-6.

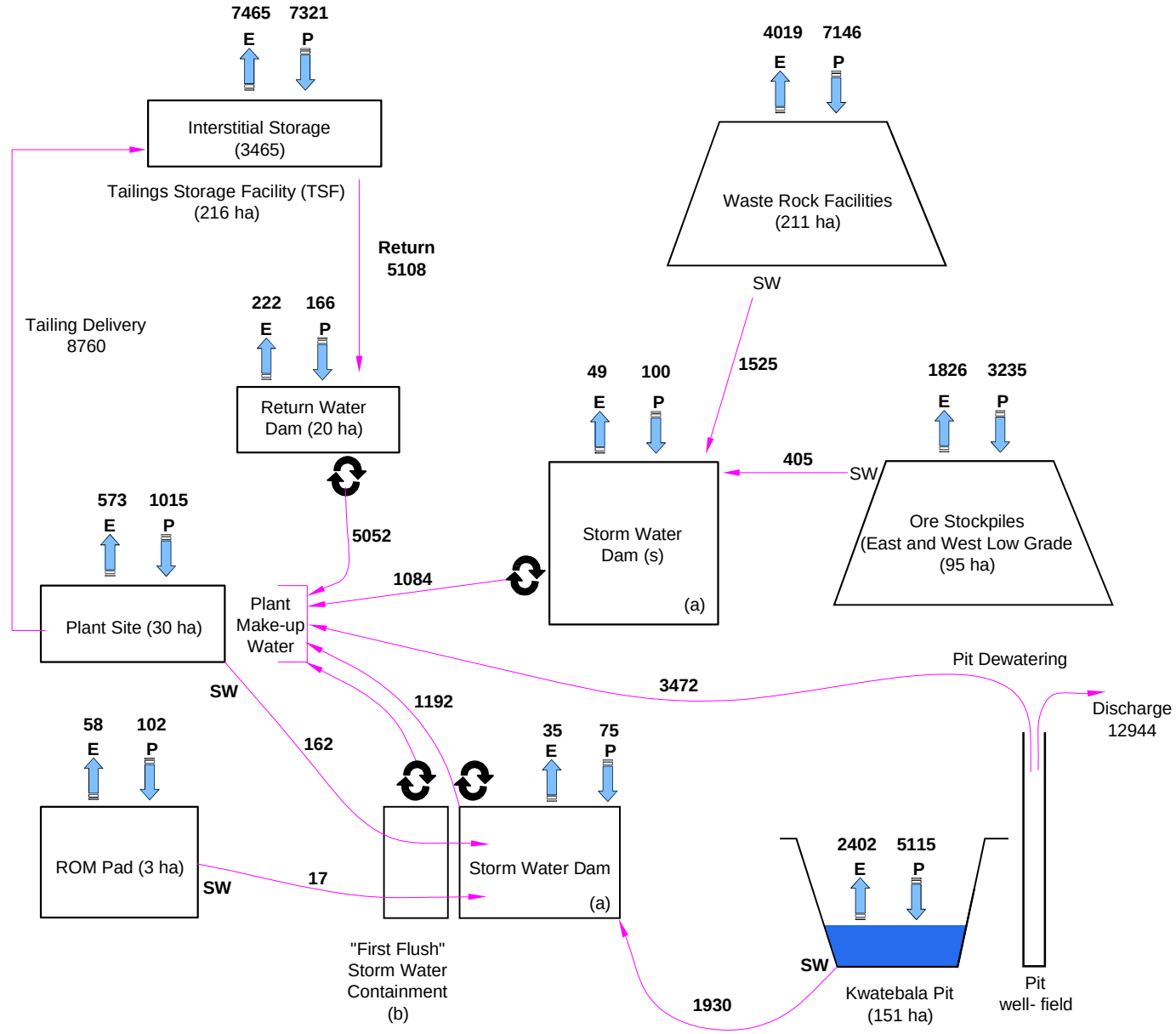
Table C2.11-6 Summary of Expected Wet Season Flows at the Monitoring Locations

Subcatchment	Catchment Area Above Gauging Station (km^2)	Percentiles of Average Daily Stream Flow (L/s)			
		5	25	50	95
upper Dipeta	8.82	5.5	16	79	250
Sokalwela	7.72	4.4	14	37	126
Shimpidi	12.0	17	32	92	299
mid Dipeta	106	90	209	717	2,584
Konka	82.0	132	234	600	2,002
lower Dipeta	233	468	969	2,419	6,110
upper Mofia	161	304	511	1,484	4,151
Kasana	10.3	20	33	95	266
mid Mofia	222	516	847	2,393	5,955
lower Mofia	389	933	1,577	4,268	10,563

km^2 = square kilometers.
L/s = liters per second.

Water Balance

A water balance model was prepared to estimate the available water for recycling to the processing plant. It also has been used to estimate the freeboard required to prevent a release of water from the tailings dam, including the probable maximum precipitation. In addition, a rainfall simulation was run to confirm that the tailings storage facility can contain multiple years of high rainfall. A simplified schematic of the project water balance is provided in Figure C2.11-3. A more detailed water balance is presented in the water balance modeling report of the Feasibility Study (MinProc 2007).



LEGEND

P	Precipitation
E	Evaporation/Evapotranspiration
SW	Storm Water
	Recycle (Make-Up Water to Process Plant)

NOTES

- All flows in cubic meters per day (m^3/day).
- Water balance provided for full facility footprints (footprint areas in hectares [ha] shown for each facility).
- Seepages reporting to groundwater not shown in this figure. A more detailed water balance (including seepages) is provided in the Feasibility Study (MinProc 2007).
- Pit groundwater dewatering values are for groundwater model Scenario b (Section C2.10).

(a) Storm water dams designed for a spill frequency of once every 10 years, on average.
(b) "First flush" storm water containment designed to capture ROM and plant site runoff from first 10 minutes of a 1 in 50 year, 24 hour storm event.
(c) Excess pit dewatering water discharged or used for streamflow mitigation.

PROJECT: TENKE FUNGURUME PROJECT

TITLE: **SCHÉMA POUR LA MOYENNE DE LA BALANCE D'EAU PAR JOUR - EAU EN SURFACE (MÈTRES CUBES PAR JOUR)/ AVERAGE DAILY WATER BALANCE SCHEMATIC - SURFACE FLOWS (m^3/day)**

Golder Associates
Calgary, Alberta

PROJECT 05-1334-035.9310			FILE No.	Water Balance
DESIGN	BR	29/03/07	SCALE AS SHOWN	REV. 0
CADD	SWD	02/04/07		
CHECK	GJ	31/03/07		
REVIEW	MR	02/04/07		

FIGURE: C2.11-3

L:\2005\1322-EA\1334\05-1334-035\9300\9310\Tailings Storage Figures\Fig C2.11-3_SCHEMATIC Water Balance-Surface Flows.dwg Apr 02, 2007 - 1:23pm

Inputs to the tailings storage facility water balance include rainfall over the tailings storage facility as well as the water in the tailings themselves. Outputs include evaporation from the pond and the tailings beach area, as well as residual water retained in the tailings indefinitely. Seepage through the tailings storage facility and return water dam (RWD) liners, which is calculated to be very minor, also is considered.

Impact Scenarios and Presentation of Results

During the first seven years, the disturbed areas of the various components and facilities making up the project will increase. Some of the facilities such as the processing plant will reach their full disturbance footprint early in the project. Other facilities, such as the pit, will gradually increase their disturbance footprint during the first seven years of the project. The impacts will be greatest at the end of the seven-year period, when facilities are at the largest they will be during this period. All impacts on flow are therefore assessed at Year 7, just prior to the start of pit dewatering (pit dewatering is predicted to begin in about Year 8, Section C2.10).

The assessment for the second time snapshot of key question SWH-1 assumes that the project facilities will be fully built out (i.e., reached their full extent in area) by Year 15 and that groundwater wells are being used to intercept flow to the Kwatebala pit.

The Goma and Fwaulu pits will not be initiated until after 2017. No detailed mine plans or groundwater data for these pits were available when the assessment was conducted. However, it is known that the mining activity will be located east of Tenke. This location is outside of the Tshilongo River catchment. If this is the case, the Dipeta River will be affected as well as local tributaries in the region of the Goma deposit. The Tshilongo River catchment will be unaffected.

Due to the uncertainties in the sewage treatment plant discharge, two flow change scenarios are presented for the Kabomboy River:

1. High-flow change scenario assuming 200 liters per person per day being released from the sewage treatment plant.
2. Low-flow change scenario assuming 80 liters per person per day being released from the sewage treatment plant.

These flow scenarios are identical for both time snapshots.

Mitigation

To mitigate the effect on flows in the streams and rivers in the area, TFM will implement the following measures:

- Develop the tailings storage facility in stages to limit the amount of disturbed and exposed areas.
- As soon as feasible, rehabilitate temporary disturbed areas through grading, revegetation and reclamation so that storm water runoff from these areas is similar to natural or pre-disturbed conditions.
- Non-contact storm water will be directed along constructed drainage paths to natural receiving water bodies.
- Predicted reductions in streamflow will be partially mitigated by discharge of groundwater to augment surface water flows. From approximately Year 8 onward (i.e., the start of pit dewatering) dry season baseflows in the Kasana, Sokalwela and Shimpidi rives will be maintained by augmenting flows with groundwater abstracted from intercept wells for pit dewatering. It is estimated that a discharge of around 15 liters per second to each river (i.e., a total discharge of around 45 liters per second) will be required to approximate dry season baseflows. Only when the dewatering volume exceeds the process water makeup requirements will groundwater abstracted for mine dewatering purposes be discharged to surface water. Groundwater modeling indicates that there should be sufficient dewatering water for both the processing plant and stream flow augmentation needs (Section A4.9.1.1).

As a reference, the predicted normal baseflows are shown in Table C2.11-7. Note that these flows are based on flows observed on site. Additional baseline surface water flow monitoring (Section D3.1.5) will confirm these flows. Use of groundwater to mitigate lost baseflows will have no effect on storm flows. As indicated above, the health of the potentially affected gallery forest and aquatic habitats should be maintained through direct discharge of water from the pit dewatering wellfield. However, there are numerous uncertainties surrounding the viability of this mitigation approach. Therefore, in addition to using available pit dewatering water for stream flow augmentation, a program to restore gallery forest habitat in stream sections within the concession not likely to be significantly affected by reduced baseflows will be implemented. The goal is to directly compensate for the possible loss of gallery forest habitat due to project impacts. In order to minimize those impacts and guide stream flow augmentation, preliminary suggested flow augmentation rates are presented in the “Effects on Baseflow” section below.

Table C2.11-7 Predicted Normal Baseflow

River	Wet Season Flow (L/s)	Dry Season Flow (L/s)
Kasana	150	15
Sokalwela	100	15
Shimpidi	150	15
Total	**400**	**45**

L/s = liters per second.

The wet season baseflows will be made up of interflow (shallow groundwater) and spring flows (deeper groundwater). Hydrographs of recorded flow data (Section B2.11) indicate that the flows in the streams during the wet season reduce fairly rapidly after storm events. This may indicate that interflow contributions cease after a few days without rain. This would then imply that the remaining flow in the streams during the wet season is a result of spring flow.

A summary of mitigation measures that will be implemented is provided in Section D3.1.5.

Results

Project Areas Affecting Stream Flow

The assessment evaluated effects for two cases: (1) assuming no baseflow augmentation in rivers; and (2) assuming baseflow augmentation is implemented. No flow augmentation is likely to be required prior to pit dewatering (Year 8).

As discussed in Section C2.11.3.1, some areas of the mine will no longer contribute to runoff while other areas will contribute more to runoff. Table C2.11-8 summarizes these areas and their effect on runoff.

Effects on Storm Flow (High Flow)

The project will result in net reductions in stream storm flow at all assessment nodes for both time snapshots except the Kabomboy River where flows will increase (Table C2.11-9). With the exception of the Kasana River, flow reductions are predicted to be less than nine percent. The Kasana River will experience the greatest reduction in flow (-45 percent to Year 7, -48 percent thereafter). Should flow augmentation be required, there would be no effect on storm flows, since flow augmentation is targeted at compensating for reduction in spring flows (i.e., groundwater discharge). The reduction in storm flow is a result of a reduction in area that contributes to storm flow and is not dependent on spring flow.

Table C2.11-8 Facilities on the Mine Site and Their Effect on Runoff

Facility	Area (ha) Year 7	Area (ha) Year 15	Affected Catchment	Effect on Runoff
tailings storage facility	216	216	Kasana	runoff to process water circuit
open pit	105	151	Shimpidi, Kasana and Sokalwela	runoff to process water circuit
waste rock facilities	172	211	Kasana	runoff to process water circuit and released to catchment
ore stockpiles	95	95	Kasana	runoff to process water circuit
processing plant areas[(a)]	30	30	Shimpidi and Kasana	runoff to process water circuit
return water dams	14.4	20	Kasana	runoff to process water circuit
run-of-mine pad	3	3	Shimpidi and Kasana	runoff to process water circuit
sewage treatment works	n/a	n/a	Kabomboy	increased runoff due to releases

(a) Plant areas generally increase the runoff.

Notes: ha = hectares.
n/a = not applicable.

Table C2.11-9 Potential Flow Changes on Storm Flow by the Project

			Year 7	Year 15	
Node	River	Catchment Area (km^2) Contributing to Flow at Node	Flow Change [(a)(b)]	Flow Change. Unmitigated Scenario [(a)(b)]	Flow Change. Mitigated Scenario [(a)(b)]
KAS1	Kasana	10.33	-45%	-48%	-48%
MOF1	Mofia	161.2	-2.9%	-3.1%	-3.1%
MOF2	Mofia	221.6	-2.1%	-2.2%	-2.2%
KAB1	Kabomboy	14.3	+2.3%[(c)]	+2.3%[(c)]	+2.3%[(c)]
KAB1	Kabomboy	14.3	+0.9%[(d)]	+0.9%[(d)]	+0.9%[(d)]
DIP1	Dipeta	106.3	-0.9%	-1.2%	-1.2%
DIP2	Dipeta	233.2	-0.4%	-0.5%	-0.5%
MOF3	Mofia	389.3	-1.2%	-1.3%	-1.3%
SOK1	Sokalwela	7.72	-1.1%	-1.4%	-1.4%
SHM1	Shimpidi	12.0	-6.9	-8.5%	-8.5%
TSH1	Tshilongo	40	0%[(e)]	0%[(e)]	0%[(e)]

(a) A reduction in flow is noted by a minus (-) sign. An increase in flow is noted by a plus (+) sign. Zero percent change represents a negligible effect.

(b) Impacts do not include the effect of the proposed mining of the Goma and Fwaulu deposits.

(c) Represents high-flow change scenario of 200 liters per person per day being released from the sewage treatment plant to the Kabomboy River.

(d) Represents low-flow change scenario of 80 liters per person per day being released from the sewage treatment plant to the Kabomboy River.

(e) The future mining activities at Goma do not appear to be in the Tshilongo River catchment.

Note: km^2 = square kilometers.

Effects on Baseflow

The TFM project has the potential to result in a net reduction in baseflow once dewatering is initiated at all assessment nodes except for the Kabomboy River, where flows will increase (Table C2.11-10). Prior to dewatering, baseflows are predicted to decrease by up to 10 percent and no mitigation is recommended. Once dewatering is initiated, flows may decrease by as much as 100 percent in the Kasana and Sokalwela rivers. Mitigation measures can reduce the impacts to the dry season baseflows to zero, except for the Kabomboy River where mitigation is not required. This can be achieved by augmenting the Kasana, Sokalwela and Shimpidi dry season flows by 15 liters per second each. Therefore, the dry season baseflows should be returned to normal if they are reduced by the dewatering program. This implies a total dry season compensation release of 45 liters per second in the dry season.

Table C2.11-10 Potential Changes to Baseflow by the Project

Node	River	Catchment Area (km^2) Contributing to Flow at Node	Year 7	Year 15		
			Unmitigated Flow Change [b][c]	Flow Change Unmitigated Scenario[b][c]	Wet Season Flow Change Mitigated Scenario[a][b][c]	Dry Season Flow Change Mitigated Scenario[a][b][c]
KAS1	Kasana	10.3	-10%	-100%	-90%	0%
MOF1	Mofia	161.2	-0.7%	-6.4%	-5.8%	0%
MOF2	Mofia	221.6	-0.5%	-4.7%	-4.2%	0%
KAB1	Kabomboy	14.3	+12.3%[d]	+12.3%[d]	+12.3%[d]	+12.3%[d]
KAB1	Kabomboy	14.3	+4.9%[e]	+4.9%[e]	+4.9%[e]	+4.9%[e]
DIP1	Dipeta	106.3	0%	-16%	-16%	0%
DIP2	Dipeta	233.2	0%	-7.2%	-7.3%	0%
MOF3	Mofia	389.3	-0.3%	-2.7%	-2.4%	0%
SOK1	Sokalwela	7.7	-10%	-100%	-85%	0%
SHM1	Shimpidi	12.0	-10%	-75%	-65%	0%
TSH1	Tshilongo	40	0%[f]	0%[f]	0%[f]	0%[f]

[a] Mitigation flow compensation for wet and dry season is assumed to be 15 liters per second for each of the following three rivers: Kasana, Sokalwela and Shimpidi (total mitigation is 45 L/s) .

[b] A reduction in flow is noted by a minus (-) sign. An increase in flow is noted by a plus (+) sign. Zero percent change represents a negligible effect.

[c] Impacts do not include the effect of the proposed mining of the Goma and Fwaulu deposits.

[d] Represents high-flow change scenario of 200 liters per person per day being released from the sewage treatment plant to the Kabomboy River.

[e] Represents low-flow change scenario of 80 liters per person per day being released from the sewage treatment plant to the Kabomboy River.

[f] The future mining activities at Goma do not appear to be in the Tshilongo River catchment.

Note: km^2 = square kilometers.

If wet season baseflow mitigation is required, mitigation should be limited to increasing the wet season baseflows in the Kasana, Sokalwela and Shimpidi rivers to approximately 12.5 percent of the normal baseflow during the wet season. (Note that this is an approximation for the purposes of the assessment. More thorough characterization of baseflow in each river will be conducted in order to derive the appropriate target for each). This will increase wet season baseflows to approximately the level of the dry season baseflows. This implies a maximum total wet season compensation of 45 liters per second for all three rivers. However, baseflows in the Shimpidi River are expected to be reduced to only 25 percent of normal wet season baseflow. If 15 1iters per second is added to the existing wet season baseflow in the Shimpidi River the expected wet season baseflow change will reduce from 75 to 65 percent (Table C2.11-10).

Effects on Total Flow

Total flow is predicted to decrease by up to 20 percent in the wet season and 10 percent in the dry season in the Kasana River prior to pit dewatering (Table C2.11-11). Once pit dewatering commences, total flow may decrease by up to 85 percent (wet) and 100 percent (dry). Monitoring will determine if these predictions are correct. At all other locations, the reductions in flow during the wet and dry season are predicted to be less than 10 percent.

Table C2.11-11 Potential Changes to Total Flow by the Project

Node	River	Catchment Area (km^2) Contributing to Flow at Node	Year 7 Flow Change [(b)(c)]		Year 15 Flow Change. Unmitigated Scenario[(b)(c)]		Year 15 Flow Change. Mitigated Scenario[(a)(b)(c)]	
			Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season
KAS1	Kasana	10.33	-20%	-10%	-85%	-100%	-78%	-90%
MOF1	Mofia	161.2	-1.3%	-0.7%	-5.4%	-6.4%	-5.0%	-5.8%
MOF2	Mofia	221.6	-0.9%	-0.5%	-4.0%	-4.7%	-3.6%	-4.2%
KAB1	Kabomboy	14.3	+3.6%[(d)]	+12.3%[(d)]	+3.6%[(d)]	+12.3%[(d)]	+3.6%[(d)]	+12.3%[(d)]
KAB1	Kabomboy	14.3	+1.5[(e)]	+4.9%[(e)]	+1.5%[(e)]	+4.9%[(e)]	+1.5%[(e)]	+4.9%[(e)]
DIP1	Dipeta	106.3	-1.7%	-1.9%	-12%	-16%	-12%	-16%
DIP2	Dipeta	233.2	-0.8%	-0.9%	-5.4%	-7.2%	-5.4%	-7.3%
MOF3	Mofia	389.3	-0.5%	-0.3%	-2.3%	-2.7%	-2.1%	-2.4%
SOK1	Sokalwela	7.72	-9.0%	-10%	-86%	-100%	-73%	-85%
SHM1	Shimpidi	12.0	-9.0%	-10%	-50%	-75%	-44%	-65%
TSH1	Tshilongo	40	0%[(f)]	0%[(f)]	0%[(f)]	0%[(f)]	0%[(f)]	0%[(f)]

[(a)] Mitigation flow compensation is 15 liters per second for the Kasana, Sokalwela and Shimpidi rivers, resulting in total mitigation of 45 liters per second. .
[(b)] A reduction in flow is noted by a minus (-) sign. An increase in flow is noted by a plus (+) sign. Zero percent change represents a negligible effect.
[(c)] Impacts do not include the effect of the proposed mining of the Goma and Fwaulu deposits.
[(d)] Represents high-flow change scenario of 200 liters per person per day being released from the sewage treatment plant to the Kabomboy River.
[(e)] Represents low-flow change scenario of 80 liters per person per day being released from the sewage treatment plant to the Kabomboy River.
[(f)] The future mining activities at Goma do not appear to be in the Tshilongo River catchment.
Note: km^2 = square kilometers.

If flow augmentation is used after Year 8, the project is predicted to result in the total flow reductions shown in Table C2.11-11. Flow is predicted to increase at only the Kabomboy River assessment location. For the Mofia and Dipeta rivers, flow reductions following mitigation at Year 15 are predicted to range from 4 to 15 percent (range is for wet and dry season flows). For the Kasana, Sokalwela and Shimpidi rivers, flow reductions following mitigation at Year 15 are predicted to range from 44 to 90 percent. Mitigation would be targeted specifically at baseflows. As a result, mitigation measures would be more effective at reducing flow changes during the dry season.

Flows will revert to close to pre-disturbance conditions after closure.

Water Balance

In an average year, the water balance model indicates that at a tailings production rate of about 6,980 tonnes per day at 54 percent moisture, about 8,760 cubic meters per day of water will enter the facility in tailings and an average of 7,321 cubic meters per day from rainfall. About 3,465 cubic meters per day will be retained indefinitely within the tailings, while about 7,465 cubic meters per day will be lost in evaporation. Seepage losses from the lined tailings storage facility will be insignificant. In an average year, the tailings storage facility will return approximately 5,108 cubic meters per day back to the return water dam, which will return 5,052 cubic meters per hour to the processing plant.

General Comments

The percentage of total flow changes in the Mofia and Dipeta rivers are smaller than the percentage of total flow changes in the tributaries. This is due to the mining activities affecting proportionally larger portions of the smaller catchments of the tributaries and affecting proportionately smaller areas of the larger Mofia and Dipeta river catchments.

Storm flows in the upper reaches of the Kasana River will be reduced due to the tailings storage facility and a portion of the processing plant being located in the headwaters of this catchment. The potential flow reduction on the storm flow is significant in the upper reaches of the Shimpidi River. This potential flow reduction is due to the ore stockpiles and the pit being located in the headwaters of this catchment. These effects are passed on to the Dipeta River where effects are assessed.

No infrastructure is located in the Sokalwela River catchment apart from the mine pit. Storm flows in the upper reaches of this small river will be reduced by a portion of the pit preventing runoff from reaching the river.

Currently, no flow changes are predicted for the Tshilongo River. This is due to the assumption that the infrastructure relating to mining activity at Goma will be located east of Tenke. This should be outside of the Tshilongo River catchment. The impacts of the mining of Goma are expected to be on the Dipeta River. The impacts of the mining of Fwaulu are expected to be mainly on the Dipeta River. The Sokalwela River catchment should be affected to a lesser degree. Impacts from the Goma and Fwaulu pits have not been quantified in this assessment as no detailed plans are available. Future ESIA work will be conducted prior to these pits being developed. Flow changes resulting from these activities will be similar to those specified in the assessments for the Dipeta and Mofia Rivers. The magnitude of the flow changes will depend on the size of the operations compared to the catchments that are affected.

All flow changes will be reversible to a large degree once the mine closes, as reclaimed mine surfaces will be designed to be free draining. Storm flow that would have been generated from this portion of the catchment will be captured by the pit. The rainfall falling on the pit will contribute to groundwater flows in the immediate area. These groundwater flows provide baseflow to surface water systems lower down in the catchment. All other areas will once again contribute runoff.

The groundwater table will recover to some extent following closure of the mine. Groundwater modeling indicates that there will be slightly lower groundwater levels near the pit, but not to the extent of preventing most spring flows from recovering. Up to about 5 springs below Kwatebala Hill may be permanently affected. All flow changes will be permanent, but most will be small. For the Kabomboy River, provided the sewage treatment plant continues to operate, flow increases due to discharge to the river will be permanent.

Impact Analysis

The magnitude of the residual effects from changes in stream flow has not been addressed in this section. These changes in stream flow have been used by other disciplines to evaluate effects of flow changes on the receptors that the respective studies deal with.

Prediction Confidence

Flow change predictions regarding surface water hydrology are generally subject to a moderate confidence as assumptions were used in the assessment. The major sources of uncertainty include:

- Assumptions associated with groundwater contributions to stream flow and a limited understanding of the aquifer boundaries.

- A limited understanding of dry season flows.
- A limited understanding of the wetting up and drying out phases of the catchments at the start and end of each wet season.
- Future mining and infrastructure placement at Goma and Fwaulu.

These sources of uncertainty are being addressed through further data collection, as described in the hydrology baseline report (Section B2.11). Flow change predictions in the Tshilongo and upper Dipeta rivers are generally subject to a low confidence as detailed mine plans relating to the mining of the Goma deposit have not been prepared. Future assessment work will be conducted to assess the potential effects of the Goma and Fwaulu pits.

Monitoring

The ESIA flow and rainfall station monitoring programs (Section D3.1.6) will be continued by TFM for at least another year to further strengthen the existing characterizations of baseline conditions. This will provide a better understanding of seasonal flows in the rivers. The data can be used for future run-of-river water supply-related projects, impact assessments for Goma and Fwaulu, and designing river diversions. A less comprehensive monitoring program will continue for the life of the mine, as described in Section D3.1.5.

Flows in the Kasana, Sokolwela and Shimpidi rivers will be monitored, as will water table levels beneath gallery forest habitat within the zone of groundwater depression (Sections C3.1 and C3.10).

C2.11.3.5 Key Question SWH-2

Key question SWH-2 is: What effect will altered stream flow have on channel geomorphology?

Linkage Evaluation

Figure C2.11-1 shows the linkage between project activities and potential effects. The linkages associated with key question SWH-2 are described in this section. Project activities during construction, operation and closure may result in changes in flows to receiving waterbodies. These changes in flow may result in changes to channel geomorphology which affect land use, water quality and fish and aquatic life. The linkages are valid.

Assessment Methods

Rivers are dynamic systems with extreme variations in flow. Due to such large natural changes in flow, channels naturally change shape or course. This typically occurs through sedimentation and erosion. Substantial changes to flow regimes affect channel morphology beyond what would naturally occur. These flow changes are typically in the order of 20 to 30 percent for peak flow increases, or a 30 to 40 percent flow reduction.

Effect of Flow Increases

The 10-year flood peak discharge was selected as a hydrologic parameter for quantifying the effects of flow increases on channel erosion and regime. The flow parameter provides a more reliable indicator for assessing the changes in the geomorphology of the natural receiving streams than other parameters, such as erosion depth and enlargement of the channel width. This is because the flow parameter can be reliably estimated. The pre-development 10-year flood peak discharge in a natural receiving stream was used as a reference discharge for calculating changes.

Flows in the Kabomboy River were not measured or simulated. Based on the land use and topography of the catchment it was assumed that flows in the Kabomboy River would resemble those in the upper Dipeta River. The 10-year flows were simulated using ACRU for the upper Dipeta monitoring point. These simulated flows were adjusted by the relative catchment size difference between the upper Dipeta and Kabomboy catchments.

Release of intercept dewatering water may be as high as 200 liters per second (approximately) to each of the Kasana, Sokalwela and Shimpidi drainages. This is within range of the storm flows in each of the three rivers. However it is about double the wet season baseflows (Section B2.11). This could cause erosion if there are continuous flows at this level.

Effect of Flow Decreases

Flow decrease could result in sedimentation of the channel. This applies to baseflow. It does not apply storm flow. Storm flow is erratic and generally has a higher flow than the baseflow, when combined with baseflow. Channel geomorphological impacts are assessed where baseflows have reduced.

Mitigation

To mitigate the effect of flow changes on channel geomorphology in the streams and rivers in the area, the project will implement the following measures:

- Erosion control measures will be selectively applied, including the development of stable embankment slopes, silt traps and prompt revegetation. These measures are intended to prevent excessive silt from being transported into the streams to prevent changes to channel morphology.
- Monitoring of river morphology (Section D3.1.12) will be conducted. If this indicates that erosion is a problem, then excess water will be piped to and released in the Dipeta River, or alternate erosion-control measures will be used.

Other mitigation is described in Section D3.1.5.

Results

Effect of Flow Increases

Channel morphological impacts relating to the project in the form of erosion may occur where the project results in an increase in flow. The only place where there is an increase in flow as a direct result of the project is at assessment node KAB1, located on the Kabomboy River. This flow increase is as a result of treated sewage effluent being released into the Kabomboy River. Indirect increases in flow due to release of dewatering water is discussed below.

The 10-year flow in the Kabomboy River was calculated as 325 liters per second. The maximum discharge from the sewage treatment plant is 200 liters per day for 2,500 workers. This equates to 5.8 liters per second. The effluent discharge will increase the 10-year flow in the Kabomboy River by less than 2.0 percent. Therefore, due to the small flow increases, effects are expected to be negligible.

Flow increases are also possible during streamflow augmentation. Release of intercept dewatering water may be as high as 200 liters per second (approximately) to each of the Kasana, Sokalwela and Shimpidi drainages at times. This is within range of the storm flows in each of the three rivers. However it is about double the wet season baseflows (Section B2.11). This could cause erosion if there are continuous flows at this level. Excess water will be piped to the Dipeta River, or erosion-control measures will be implemented, to mitigate these effects.

Effect of Flow Decreases

Channel geomorphology impacts may occur where baseflows have been reduced. However, after mitigation, baseflows will probably not be significantly impacted during the dry season (see Table C2.11-10). During the wet season, the baseflows are significantly reduced at assessment nodes KAS1, SOKI and SHMI (i.e., the magnitude of stream reduction is greater than 40 percent, resulting in a high impact – Table C2.11-3). Storm flows are also significantly reduced at KAS1 (Table C2.11-9). The reduction in flow will result in a decrease in flow velocity. However, these rivers are relatively steep and fast flowing. The flows are to be fast and turbulent enough to keep the sediment load in suspension. For this reason it is not anticipated that sedimentation due to flow reductions will occur at assessment nodes KAS1, SOKI or SHMI.

The flows at all other assessment nodes are not predicted to be changed sufficiently to result in increased sedimentation.

Impact Analysis

A negligible environmental consequence is predicted for the effects of flow increases on channel geomorphology (Table C2.11-12). The increase in flows predicted for the Kabomboy River are estimated to be only 1.8 percent. The effect of flow decreases is predicted to be negligible as mitigation should restore dry season baseflows to close to their pre-disturbance levels.

Table C2.11-12 Residual Impact Classification for SWH-2

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key Question SWH-2: What effect will altered stream flow have on channel geomorphology?						
Effect of flow increases						
negative	negligible	local	medium-term	yes	high	negligible
Effect of flow decreases						
negative	negligible	local	medium-term	yes	high	negligible

Prediction Confidence

Flow change predictions regarding surface water hydrology were made with a high confidence as conservative assumptions were used in the assessment.

Monitoring

Monitoring of changes in stream flow and channel morphology will include, as discussed in Section D3.1.5 and D3.1.12:

- Monitoring downstream flows.
- Visual assessments of channel geomorphology.

Operations and water management at the mine site will be adjusted as necessary to maintain stream flow and minimize changes to channel morphology.

C2.11.3.6 Key Question SWH-3

Key question SWH-3 is: What effect will altered stream flow have on water supply?

Linkage Evaluation

Figure C2.11-1 shows the linkage between project activities and potential effects. The linkages associated with key question SWH-3 are described in this section. Project activities during construction, operation and closure may result in changes in flows to receiving waterbodies. These changes in flow may result in changes to volumes of water available for water supply. The linkages are valid.

Assessment Methods

Only the village of Mwanga Muteba withdraws water from local rivers and springs that could be affected by the project (Figure C2.11-2). Flow changes with respect to water supply therefore are only assessed on the Kasana River, at node KAS1 near the village.

Mitigation

Dry season baseflow in the Kasana River will be maintained by augmenting flows with water abstracted for mine dewatering. The amount of augmentation that will be required is represented by the "Dry Season Flow" indicated in Table C2.11-13.

Table C2.11-13 Volumes of Water That Need to Be Released to Mitigate the Drying Up of Springs

River	Wet Season Flow (L/s)	Dry Season Flow (L/s)
Kasana	150	15
Sokalwela	100	15
Shimpidi	113[(a)]	15
Total	**363**	**45**

L/s = liters per second

[(a)] Equivalent to 75 percent of estimated baseflow (i.e., 75% of 150 L/s)

Results

The local residents usually use only a fraction of the water that flows past assessment node KAS1. Water is drawn using buckets and other manual means. Baseflow assurance levels of supply are far more important than peak flow assurance levels of supply. This results in communities being more dependent on baseflows. Peak flows have little bearing on water supply. Baseflows are mostly fed by springs during the wet season and totally fed by springs during the dry season. Mitigation of baseflow impacts can reduce water supply impacts to zero.

Unmitigated and mitigated flow change scenarios were assessed at assessment node KAS1:

- For the unmitigated scenario, baseflow reductions of 100 percent of flows in the wet and dry season are predicted (Table C2.11-10).
- With dry and wet season flow mitigation, water would be provided by maintenance of some flow year round (Table C2.11-14). Streamflow mitigation will include discharge of 15 liters per second to the Kasana river year round.

Table C2.11-14 Potential Impacts of the Project on Water Supply – Baseflow Conditions

Node	River	Catchment Area (km^2) Contributing to Flow at Node	Flow Change Unmitigated Scenario[(a)(b)(c)]		Flow Change Mitigated Scenario[(a)(b)(c)(d)]	
			Wet Season[(b)]	Dry Season[(b)]	Wet Season[(b)]	Dry Season[(b)]
KAS1	Kasana	10.33	-100%	-100%	-90%	0%

[(a)] The scenarios are described in the paragraph preceding the table.

[(b)] A reduction in flow is noted by a minus (-) sign. An increase in flow is noted by a plus (+) sign. Zero percent change represents a negligible effect.

[(c)] Impacts do not include the effect of the proposed mining of the Goma and Fwaulu deposits.

[(d)] Mitigation flow compensation is 15 liters per second to the Kasana River.

- If streamflow mitigation is not sufficient to supply drinking water needs, in the event of contamination or significant reduction in surface water availability directly linked to mining operations, alternative drinking water sources will be provided (e.g., TFM will provide a potable groundwater source to residents of Mwanga Muteba, the only village that exists in proximity to the mine that may be affected by changes in water quantity).
- Groundwater modeling results indicate that wells sited in the village would be outside the steady-state zone of influence of post-closure mine facilities (Appendix C2.10-I). A well sited in the village would therefore be outside the area that could be affected by seepage from the stockpiles and tailings ponds.

If this is not sufficient to supply drinking water needs to the village of Mwanga Muteba, alternative drinking water sources will be provided.

Prediction Confidence

Flow change predictions regarding surface water hydrology are made with a moderate confidence. The major sources of uncertainty include:

- Assumptions associated with groundwater contributions to stream flow.
- A limited understanding of dry season flows.
- A limited understanding of the wetting up and drying out phases of the catchments at the start and end of each wet season.
- Future hydrological infrastructure location.

These sources of uncertainty are being addressed through further hydrological data collection (Section D3.1.5).

While flow change predictions are made with moderate confidence, impacts on water supply are made with high confidence. Flow reductions in streams will be compensated by using pit dewatering water to augment spring flow (i.e., groundwater recharge to streams). This would be a dynamic process. Compensation flows can be changed depending on the amount of spring flow that is lost.

Monitoring

The flow monitoring program is fully described in Section D3.1.5. This program will provide a better understanding of seasonal flows in the rivers. The data can be used for future run-of-river water supply related projects and impact assessments.

C2.11.4 Cumulative Effects Assessment

Linkage Evaluation

Should the project be expanded from a production of 115,000 tonnes of copper per year to a 400,000 tonnes per year operation, the physical extent of waste rock facilities, tailings storage facilities and other mine-related facilities would increase. These facilities would affect surface water hydrology. This linkage is valid.

Assessment Methods

Detailed plans for the additional development of the project to expand to 400,000 tonnes of copper per year are not yet available. Also, little information on groundwater conditions in the vicinity of the Goma and Fwaulu pits is available. Conceptual layouts of areas to be mined are available. The general concept for such a development was reviewed in the context of known baseline conditions for surface water hydrology. Professional experience in relation to changes in flows generally caused by mining, processing plant sites, waste rock facilities, quarries and linear developments (such as roads, airstrip) was used to develop an understanding of the potential effect of an expanded project. Principles developed for closure plans and other project goals for long-term mitigation of effects were used to develop an assessment of long-term flow changes.

Mitigation

In addition to the mitigation measures proposed for key question SWH-1, an expanded 400,000 tonnes per year project would have to create a more detailed plan for catchment restoration. This is due to the greater level of impact on the Dipeta and Mofia rivers and their tributaries. Since the geographic extent of the project would increase, other tributaries would likely need to be studied.

Results

The effects on surface water hydrology with a larger, 400,000 tonnes per year project would be greater in magnitude than those predicted for key question SWH-1. The types of impacts expected would be very similar. New waste rock facilities, dams and ore stockpiles would be developed, possibly in other catchments. These would be rehabilitated after closure, but the additional pits would be a permanent feature. Three to four times the land area of the project would be affected in such a cumulative development case, depending on economies of scale and advances in technology that can help to reduce this impact.

The impacts caused by an expanded project will be directly related to the footprint areas of facilities such as tailings dams, waste rock facilities, contact areas of the plant, etc. Additional streams such as the Kampangu and the Kiomba may be impacted. The Dipeta and Mofia rivers will be further impacted. Table C2.11-15 shows a rough estimate of what impacts could be experienced in an expanded project.

Table C2.11-15 Estimated Potential Changes to Total Flow by the Expanded Project

Node	River	Catchment Area (km^2) Contributing to Flow at Node	Flow Change. Unmitigated Scenario[a][b][c]		Flow Change. Mitigated Scenario[a][b][c]	
			Wet Season	Dry Season	Wet Season	Dry Season
KAS1	Kasana	10.33	-85%	-100%	-78%	-90%
MOF1	Mofia	161.2	-5.4%	-6.4%	-5.0%	-5.8%
MOF2	Mofia	221.6	-5.0%	-6.0%	-5.0%	-5.5%
KAB1	Kabomboy	14.3	+3.6%[d]	+12.3%[d]	+3.6%[d]	+12.3%[d]
KAB1	Kabomboy	14.3	+1.5%[e]	+4.9%[e]	+1.5%[e]	+4.9%[e]
DIP1	Dipeta	106.3	-40%	-50%	-30%	-40%
DIP2	Dipeta	233.2	-10%	-12%	-10%	-12%
MOF3	Mofia	389.3	-2.3%	-2.7%	-2.1%	-2.4%
SOK1	Sokalwela	7.72	-95%	-100%	-80%	-85%
SHM1	Shimpidi	12.0	-50%	-75%	-44%	-65%
	Kampangu	15.5	-35%	-50%	-30%	-25%
	Kiombo	8.5	-15%	-25%	-10%	-5%
TSH1	Tshilongo	40	0%[f]	0%[f]	0%[f]	0%[f]

[a] Mitigation flow compensation similar to what is proposed for the impact mitigation as a result of the Kwatebala pit.
[b] A reduction in flow is noted by a minus (-) sign. An increase in flow is noted by a plus (+) sign. Zero percent change represents a negligible effect.
[c] All impacts based on estimated footprint areas, facility locations, facility types and dewatering impacts.
[d] Represents high-flow change scenario of 200 liters per person per day being released from the sewage treatment plant to the Kabomboy River. Possible population increase for the expanded project has not been included in assessment.
[e] Represents low-flow change scenario of 80 liters per person per day being released from the sewage treatment plant to the Kabomboy River. Possible population increase for the expanded project has not been included in assessment.
[f] The future mining activities at Goma do not appear to be in the Tshilongo River catchment. There is no anticipated groundwater impact.

Note: km^2 = square kilometers.

Residual impacts are provided in Table C2.11-16. Residual flow changes caused by mining on surface water hydrology will be minimal, but permanent. The mine site will be rehabilitated, thus returning channel drainage back to normal. The pits (including Kwatebala) will likely to be sources of recharge to the groundwater system. Long-term groundwater level changes as a result of

evaporation from the open pits are unknown at this stage. The groundwater levels affect spring flows in the rivers. Two scenarios were therefore looked at:

- **High flow change** – Assumes that spring flows will be reduced by 25 percent in the long-term in the Kasana, Kiomba, Kampangu and Sokalwela rivers. This scenario assumes that the spring flows in the Shimpidi River are reduced by 10 percent.
- **Low flow change** – Assumes that spring flows recover completely.

Table C2.11-16 Residual Impact Classification for the Cumulative Case

Node	River	Catchment Area (km^2) Contributing to Flow at Node	Flow Change - High Flow Change Scenario[a][b]		Flow Change - Low Flow Change Scenario[a][b]	
			Wet Season[c]	Dry Season[c]	Wet Season[c]	Dry Season[c]
KAS1	Kasana	10.33	-19%	-25%	-1.1%	0%
MOF1	Mofia	161.2	-1.5%	-2%	-0.1%	0%
MOF2	Mofia	221.6	-1.0%	-1.5%	-0.1%	0%
KAB1	Kabomboy	14.3	+3.6%[d]	+12.3%[d]	+1.5%[d]	+4.9%[d]
DIP1	Dipeta	106.3	-15%	-20%	-12%	-15%
DIP2	Dipeta	233.2	-12%	-15%	-5%	-10%
MOF3	Mofia	389.3	-1.0%	-1.0%	0%	0%
SOK1	Sokalwela	7.72	-22%	-25%	-0.2%	0%
SHM1	Shimpidi	12.0	-18%	-25%	-2.5%	0%
	Kampangu	15.5	-15%	-25%	0%	0%
	Kiombo	8.5	-15%	-25%	-2.5%	0%
TSH1	Tshilongo	40	0%[e]	0%[e]	0%[e]	0%[e]

[a] The scenarios are described in the paragraph preceding the table.

[b] Impacts include estimated effects of the proposed mining of the Goma and Fwaulu deposits. These estimates are based on estimated footprint areas, facility locations, facility types and dewatering impacts.

[c] A reduction in flow is noted by a minus (-) sign. An increase in flow is noted by a plus (+) sign.

[d] The sewage treatment plant is assumed to continue operating after the closure of the mine.

[e] The future mining activities at Goma do not appear to be in the Tshilongo River catchment. Detailed mine plans will confirm this when they are drafted at a later stage.

Note: km^2 = square kilometers.

Most of the residual effects are a result of the potential spring flow reductions. The effect of the mine pits on surface flow is minimal. This effect can be seen in the results of the low impact scenario, where it is assumed that no long-term spring flow reductions occur. The pits will capture rainfall within their footprint, and therefore will affect wet season flows as rainfall falling on their footprints will not contribute to runoff.

The residual flow changes predicted for the Dipeta River assume that an attenuation dam is constructed prior to mining of the Goma deposit. This dam is assumed to be a permanent structure that remains in place at closure.

Impact Analysis

For the cumulative case, flow changes will occur across much of the LSA including the Goma and Fwaulu hills as well as additional ore-bearing hills outside of the LSA, such as the Fungurume hills. This expanded project would cover considerably more land area than those in the project case assessed under key question SWH-1.

All flow changes will be reversible to a large degree once the mine closes. Similar to Kwatebala, these pits will likely be sources of recharge to the groundwater system. Storm flow that would have been generated from these portions of the catchment will be captured by the pit. Groundwater flow will feed surface water systems lower down in the catchment. All other areas will contribute to runoff once again. The groundwater table will recover following closure of the mine. The groundwater levels near the pit may be slightly lower, but not to the extent of preventing spring flows from recovering. The impacts of these effects will be larger in local subcatchments than in the larger regional catchments. A full assessment of the potential effects of the Goma and Fwaulu pits will be conducted prior to their development.

Prediction Confidence

Impact predictions regarding surface water hydrology are generally subject to a moderate confidence as assumptions were used in the assessment. Information concerning the effects of a larger, 400,000 tonnes per year project is limited, but a general understanding of the effects of such a project is in place. The major sources of uncertainty include those associated with:

- Assumptions associated with groundwater contributions to stream flow.
- A limited understanding of dry season flows.
- A limited understanding of the wetting up and drying out phases of the catchments at the start and end of each wet season.
- Future infrastructure location.

These sources of uncertainty will be addressed through further hydrology and groundwater data collection. However, based on the results of the assessment, no fatal flaws for surface water hydrology that would prevent expansion of the project are expected.

C2.11.5 Conclusions

Surface water hydrology impacts result in a change in flow. The impact of a change in flow cannot be assessed in itself. It can only be assessed when the change in flow has a consequential benefit or disadvantage on a receptor. Most receptors that may be impacted by flow changes in the rivers are dealt with in other specialist disciplines. These include receptors such as fish and aquatic habitat (Section C3.3), water quality (Section C2.12) and socio-economics (Section C4.1). The impacts of flow changes on these disciplines are described in their respective impact studies. The surface water hydrology impact assessment provides information for these studies to conduct impact assessments. The effects on channel morphology were covered in this assessment and the impacts described and quantified in this assessment. The assessment criterion for surface water hydrology excludes a magnitude category for surface water hydrology impacts, except for channel morphology impacts.

Nine assessment nodes were identified in consultation with the water quality, fish and aquatic habitat and social specialists. There is one node on the Kasana River, two nodes on the Dipeta River, three on the Mofia River, one on the Kabomboy River, one on the Sokalwela River, one on the Shimpidi River and one on the Tshilongo River. Flows at all nodes, except for the Kabomboy River node, will be reduced as a result of the mining activities. This is due to areas that would have contributed to stream flow being used for mining-related activities. The runoff from these areas, which would be classified as contact water, will be captured and used in the process water circuits. These areas will include the mine pit, the tailings storage facility, contact areas of the processing plant, process water dams and the ore stockpiles.

Mine dewatering will occur in order to maintain a dry pit. Groundwater modeling results show that the local water table will be lowered, affecting the spring flows and baseflows in the Kasana, Sokalwela and Shimpidi rivers. The modeling results indicate that baseflows may be totally depleted in the Kasana and Sokalwela rivers and mostly depleted in the Shimpidi River. This may have a significant effect on baseflows in these rivers, possibly drying up the Kasana and Sokalwela rivers during the dry season. These flow reductions have subsequent effects on the Mofia and Dipeta rivers. Direct influences (reductions) on the Dipeta River are also expected to occur. The percentage of the total flow reductions in the Mofia and Dipeta rivers would be significantly less than the flow reductions in the tributaries of these two rivers. This is due to the affected areas being proportionally smaller in larger catchments such as the Dipeta and Mofia, compared to smaller tributary catchments. Mitigation by means of stream flow augmentation after Year 7 will increase lost baseflows.

Flows to the Kabomboy River catchment will be increased due to release of treated effluent from the sewage treatment to the Kabomboy River.

Flow changes predicted for Year 7 (before pit dewatering) and Year 15 (after pit dewatering) are summarized in Table C2.11-17. Total wet season flows are predicted to decrease by up to 78 percent, but this should not influence water users as only a small percentage of stream flow is used during the wet season. Total dry season flows are expected to be reduced by up to 90 percent.

Table C2.11-17 Potential Flow Changes on Total Flow by the Project

Node	River	Mitigated Flow Change Year 7[(a)]		Mitigated Flow Change Mine Closure (Year 15)[(a)]	
		Wet Season	Dry Season	Wet Season	Dry Season
KAS1	Kasana	-20%	-10%	-78%	-90%
MOF1	Mofia	-1.3%	-0.7%	-5.0%	-5.8%
MOF2	Mofia	-0.9%	-0.5%	-3.6%	-4.2%
KAB1	Kabomboy	+3.6%[(b)]	+12.3%[(b)]	+3.6%[(b)]	+12.3%[(b)]
KAB1	Kabomboy	+1.5%[(c)]	+4.9%[(c)]	+1.5%[(c)]	+4.9%[(c)]
DIP1	Dipeta	-1.7%	-1.9%	-12%	-16%
DIP2	Dipeta	-0.8%	-0.9%	-5.4%	-7.3%
MOF3	Mofia	-0.5%	-0.3%	-2.1%	-2.4%
SOK1	Sokalwela	-9.0%	-10%	-73%	-85%
SHM1	Shimpidi	-9.0%	-10%	-44%	-65%
TSH1	Tshilongo	0%[(d)]	0%[(d)]	0%[(d)]	0%[(d)]

[(a)] Key question SWH-1, Section C2.11.3.4.

[(b)] Represents high-flow change scenario of 200 liters per day being released from the sewage treatment plant to the Kabomboy River.

[(c)] Represents low-flow change scenario of 80 liters per day being released from the sewage treatment plant to the Kabomboy River.

[(d)] The future mining activities at Goma do not appear to be in the Tshilongo River catchment. Detailed mine plans will confirm this when they are drafted at a later stage in the mine's development.

Release of excess dewatering water may cause erosion in local rivers. Erosion will be monitored and actions taken should this prove to be an issue (Section C3.1.5).

All flow changes will be reversible to a large degree once the mine closes. The mine pit will likely be a source of recharge to the groundwater system. Storm flow that would have been generated from this portion of the catchment will be captured by the mine pit. Groundwater flow will feed surface water systems lower down in the catchment. All other areas will contribute to surface runoff once again. The groundwater table will recover following closure of the mine. The pit may result in lower groundwater levels, but not to the extent of preventing the spring flows from recovering. All flow changes will be permanent, although significantly reduced.

Monitoring

The monitoring program established will be continued during the life of the mine. This will benefit the personnel involved with the monitoring program by providing a small income and enhancing their skills. TFM will gain a better understanding of how the catchments respond to rainfall and what flows can be expected in the rivers. This information can be used in the future for impact assessment and mine planning in terms of water supply and storm water management. The information may also be useful to the broader scientific community. The monitoring program is not a long-term benefit and will cease once the mine closes, unless the broader scientific community continues with the program.

Flows, erosion and channel morphology in the Kasana, Sololwela and Shimpidi rivers will be monitored (Sections D3.1.5 and D3.1.12), as will water tables beneath of gallery forest habitat downstream of the mine (Section D3.1.6).

C2.12 WATER AND SEDIMENT QUALITY

C2.12.1 Introduction

This section presents the environmental assessment for the effects of the Tenke Fungurume Mining (TFM) project on water and sediment quality. The information presented in this section meets the terms of reference for the project (Appendix E8) and includes details on:

- Components within each phase of the project that may influence or affect surface water and sediment quality.
- Concerns identified by stakeholders and regulators.
- Impact assessment (using qualitative and quantitative methods) for potential impacts of the project on surface water and sediment quality within the study areas.
- Sustainability assessment for key surface water and sediment quality issues.
- Proposed mitigation measures to be considered during the construction, operation and reclamation phases of the project to maintain surface water and sediment quality.
- The monitoring program that will be used to identify and monitor project impacts on surface water and sediment quality.

This section of the environmental and social impact assessment (ESIA) is organized as follows:

- Section C2.12.2 describes the study areas.
- Section C2.12.3 discusses the approaches and results for the impact and sustainability assessments.
- Section C2.12.4 discusses the cumulative effects assessment.
- Section C2.12.5 discusses the conclusions of the impact assessment.

Existing surface water, groundwater and sediment quality is described in the water and sediment quality baseline report (Section B2.12). A glossary of terms and acronyms used in this section is provided at the end of the volume.

C2.12.2 Study Areas

The Regional Study Area (RSA) covers the Mofia River and the Dipeta River catchments and a small portion of the Tshilongo River catchment near Tenke. Proposed and potential future mining activities in the TFM concession will occur within these areas (Figure C1.5-1).

Although the TFM project will include pits at Goma, Fwaulu and Kwatebala, the assessment is for the Kwatebala pit only. The area where mining of Kwatebala hill and its associated activities have the potential to directly impact surface water comprises the Local Study Area (LSA) (Figure B1.5-1). The mine site is located in the upper Dipeta, Shimpidi, Sokalwela and Kasana river catchments. The airstrip, limestone quarry and permanent village will be located in the Kabomboy River catchment. Changes in these catchments also have the potential to impact the Dipeta and Mofia rivers. Construction and operation of access roads have the potential to cause localized effects in a number of other subcatchments of the Mofia and Dipeta rivers.

C2.12.3 Impact Assessment

C2.12.3.1 Issue Scoping

The TFM project has the potential to affect surface water, groundwater and sediment quality as a result of a number of activities, including:

- Site preparation and clearing.
- Diversion and disruption of natural drainage lines.
- Dewatering and subsequent decrease in flows.
- Disposal and stockpiling of waste rock and ore.
- Ore processing activities.
- Discharge of treated sewage effluent.
- Accidental releases and spills.
- Site reclamation and closure activities.

Stakeholders identified many of the above activities as concerns and had additional specific concerns. The potential for toxic effects from the tailings storage facility was an issue raised often by stakeholders. Stakeholders are concerned that the quality of water would be affected by toxins from the tailings storage facility and effluent pollution from the processing plant and mine. Heavy

metal pollution, especially lead pollution, is of particular concern. Others expressed concern that the removal of trees and vegetation near rivers will cause erosion which, in turn, may cause reduced water quality. Stakeholders were also concerned about the potential presence of radioactivity in the ore and subsequent effects to human health and safety. In the Kambove area west of Likasi, approximately 40 kilometers away, some of the copper and cobalt ore has a trace of radioactivity.

The major surface water uses in the project concession include bathing and laundry, potable (drinking water) consumption, agricultural irrigation and use to sustain natural habitats and species. Surface waters are also used as latrines by some of the population and, until the end of 2005, were used for washing of heterogenite and copper ores by artisanal miners at some locations. Currently, surface water quality may be affected by runoff from artisanal mining operations, urban centers and agricultural land (Section B2.12).

The linkages between project activities and potential effects on water and sediment quality are depicted in Figure C2.12-1. Potential surface water and sediment quality effects could occur during all phases of the project, including construction, operations, closure and post-closure. The key questions used to guide this assessment are also shown. Results of this assessment that were used in another component of the ESIA are shown to the right.

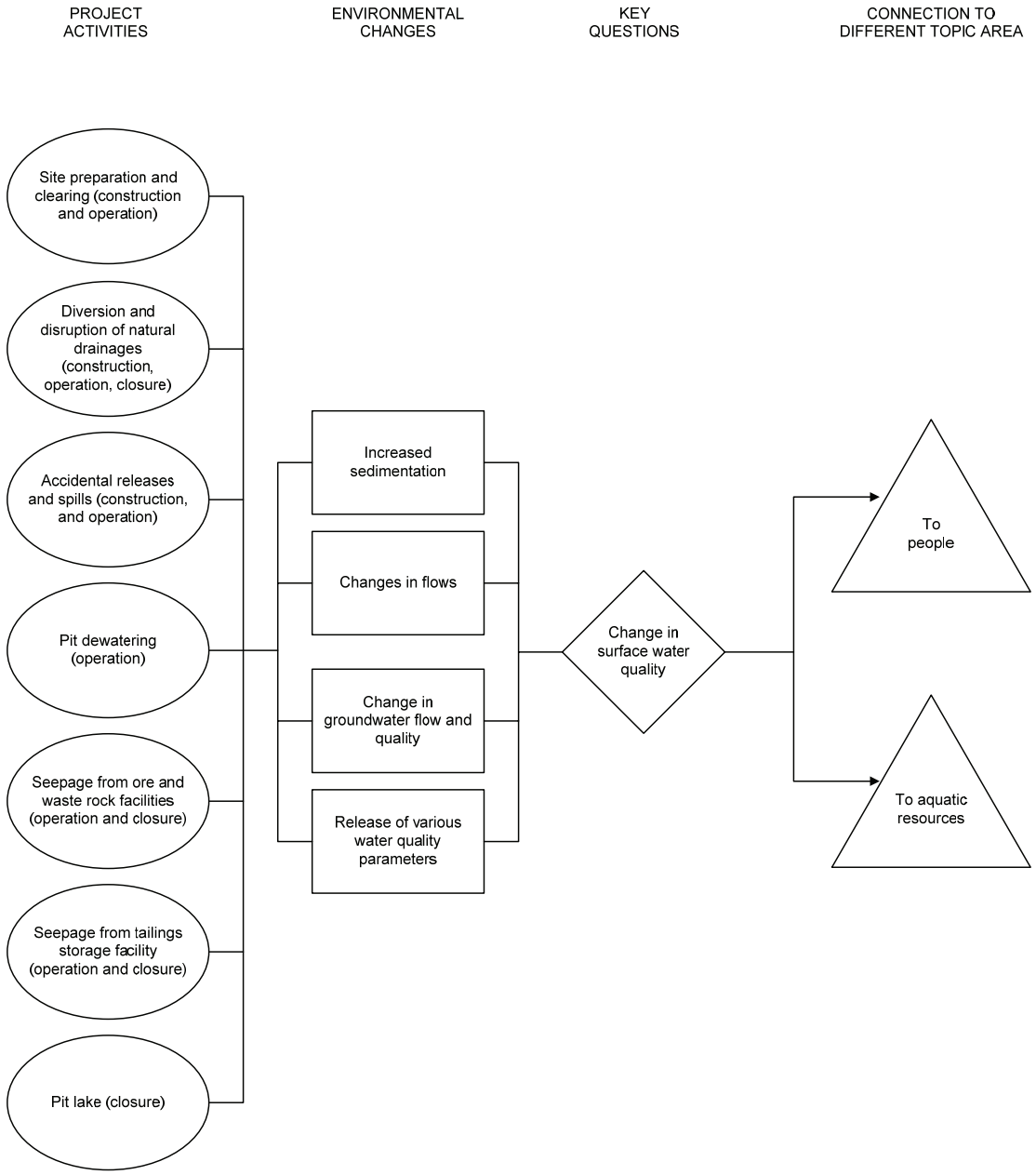
C2.12.3.2 Key Questions and Indicators

The linkages shown in Figure C2.12-1 were assessed by answering key questions for water and sediment quality (Table C2.12-1). The use of linkage analysis and key questions is described in Section A5.

Table C2.12-1 Key Questions for Water Quality

Impact Assessment
WQ-1 What effect will the project have on water quality indicators in local watercourses?
WQ-2 What effect will the project have on sediment quality in local watercourses?
WQ-3 What are the predicted water quality characteristics of the pit lake?
Sustainability Assessment
WQ-4 How can the project have a positive effect on water and sediment quality?

Figure C2.12-1 Water and Sediment Quality Linkage Diagram



Both the Global Reporting Initiative (GRI 2006) and International Federation of Consulting Engineers (FIDIC 2004) have identified indicators for surface water quality. Table C2.12-2 provides a description of these indicators and how these have been adapted for use in the ESIA. These indicators are used to assess potential effects of the project on water quality.

Table C2.12-2 Water Quality Indicators

GRI/FIDIC Indicators	ESIA Indicators
GRI - EN12. significant effluent discharges to water by type	predicted effluent water quality at point of discharge compared to guidelines and background concentrations for a comprehensive suite of parameters
GRI - EN32. water sources and ecosystems/habitats significantly affected by use of water	predicted water quality in surface water compared to guidelines and background concentrations for a comprehensive suite of parameters
FIDIC – EN14. measurements of biological oxygen demand on water bodies affected by project during all phases	predicted biological oxygen demand at point of discharge and in surface water
FIDIC - EN11. measurements of changes in algae concentrations	predicted water quality in surface water compared to guidelines and background concentrations for a comprehensive suite of parameters
FIDIC – EN15. measurements of fecal coliform in freshwater bodies affected by project during all phases	n/a – coliform monitoring in surface water will be included in the environmental action plan (Section D3)

C2.12.3.3 Assessment Criteria

Table C2.12-3 provides the impact description criteria used to quantify changes in indicators as described in Section A5.1.7.

C2.12.3.4 Key Question WQ-1

Key question WQ-1 is: What effect will the project have on water quality in local watercourses?

Linkage Evaluation

Figure C2.12-1 shows the linkage between project activities and potential effects. The linkages associated with key question WQ-1 are described in this section.

Table C2.12-3 Impact Description Criteria for Water Quality

Direction[a]	Magnitude[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
positive, **negative** or **neutral** for the measurement endpoints	**negligible**: releases do not cause guidelines or existing backgrounds to be exceeded **low**: releases contribute slightly to existing background being exceeded **moderate**: releases cause the guidelines to be exceeded (where guidelines were not previously exceeded) **high**: releases cause the guidelines to be exceeded substantially	**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 20 years **long-term**: >20 years	**reversible** or **irreversible**	**low**: occurs once or rarely **medium**: occurs intermittently **high**: occurs continuously

[a] Direction: positive or negative effect for measurement endpoints, as defined for 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 two-year construction period and a 20-year operation period.

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

[f] Frequency: how often the environmental effect occurs.

Changes in Groundwater Flow

Changes in groundwater flow due to changes in infiltration and groundwater extraction (removal) for process water have the potential to affect the contribution of groundwater to surface water and, as a result, the combined water quality.

The hydrology assessment (Section C2.11) showed that there could be a change in groundwater flow to streams in the LSA and the linkage was considered to be valid.

Changes in Groundwater Quality

The tailings storage facility will be lined to minimize seepage to surface water. However, the hydrogeology assessment (Section C2.10) showed that this seepage rate is not likely to be zero (although extremely close), even with a well engineered and constructed liner. Therefore, this linkage was considered to be valid.

The ore stockpiles and waste rock facilities will not be underlain by a low permeability liner and there will be some seepage (Section C2.10). This linkage was considered to be valid.

The pit lake will not have a surface discharge but pit lake recharge to groundwater will eventually discharge to surface water in the local study area after the mine closure (Section C2.10). This linkage was considered to be valid.

Changes in Amount of Surface Water Runoff

Mine activities have the potential to affect the amount of surface runoff as a result of containment of runoff water from ore stockpiles, the waste rock facility, the limestone quarry, the tailings storage facility and the processing plant. Changing surface water runoff could have an effect on water quality in nearby watercourses. The hydrology assessment (Section C2.11) showed that changes in stream flows in the LSA were dominated by changes in groundwater flow during the dry season and that changes in surface runoff did not greatly affect stream flow. In the wet season, the change in surface water flow would not affect surface water quality because the proportion of groundwater in stream flows would not change substantially. As a result, the linkage between changes in surface water flow and changes in water and sediment quality was considered to be invalid.

Changes in Sedimentation and Quality of Runoff

Construction

Site preparation, site clearing and construction of roads and other facilities have the potential to result in increases in suspended sediment loadings and of sedimentary-bound contaminants to receiving water bodies. This linkage was considered to be valid.

Operation

During operation, the water quality of runoff from different land types within the mine area and the limestone quarry may be different than the water quality of runoff during baseline conditions. Changes in the quality of runoff could result from leaching of metals from ore stockpiles and the waste rock facilities and increased runoff, which has the potential to increase erosion and sedimentation.

Ore Stockpiles, Waste Rock Facilities and Processing Plant Site

The surface water management plan (Section A4.9) includes capture of storm water runoff (i.e., contact water runoff) from mine waste facilities and use of this water within the process water circuit. Non-contact runoff will be channeled around the waste rock facilities and ore stockpiles. These channels will be inspected and maintained as part of the water management system for the waste rock facilities. Storm water runoff from the processing plant site and the run-of-mine (ROM) pad will be collected in storm water ponds for use in the process water circuit.

Runoff from the ore stockpiles, the waste rock facilities, Kwatebala pit and ROM pad will normally be captured and tested for water quality prior to release, treatment, and/or use within the process plant. When meeting all applicable water quality standards, storm water may be released during the wet season to manage the amount of water retained within the water circuit. However, if the water inventories exceed the containment capacity of the facility, a discharge of untested and untreated storm water may occur. The Tenke Fungurume facility is designed to limit this kind of discharge to a frequency of less than once every ten years, on average. The south retention pond, which contains water from Kwatebala pit and the ROM pad, is predicted to spill to surface water at a frequency less than once in 50 years. Because the frequency is extremely low, and based on conservative model assumptions, the linkage was considered to be invalid.

The linkage between storm water runoff and surface water quality was therefore considered to be invalid for typical operating conditions but valid for storm flow during a 1 in 10 year storm event.

Limestone Quarry

A site visit to the limestone quarry location demonstrated that runoff water from the limestone quarry site will not reach surface waters (Appendix B2.3-II). The linkage between runoff from the limestone quarry site and surface water quality was considered to be invalid.

Post-Closure

After closure, water quality could be affected as a result of water releases from pits and reclaimed areas. A reclamation landscape with sustainable drainage and vegetation cover will be established at closure to prevent runoff water from coming into contact with mine or waste material and to minimize erosion (Section D5). The pit lake will not drain to surface water because of the topography of the catchment and runoff quality from the 'capped' reclaimed areas will be equivalent to baseline runoff quality. The linkage between surface runoff and water quality at closure (excluding water quality of the pit lake) was considered to be invalid. At closure, if hydrologic and water quality conditions allow, a surface water outlet from the pit lake may be considered to stabilize seasonal flows in downstream reaches of the drainage (Section D3.1.14.3). Water quality of the pit lake is assessed in Appendix B2.3-I. The pit lake will likely be a source of recharge to the groundwater system (Section C2.10) and subsequently surface water. The effect of this seepage (i.e., recharge to groundwater) from the pit lake to surface waters was assessed and was found to be of low environmental consequence (Table C2.12-9).

Liquid Effluents

Water quality in the receiving environment may also be affected during construction and operation of the mine as a result of wastewater (effluent) releases. Potential wastewater releases include sewage and water from mine pit dewatering and tailings effluent (waste).

The water management plan (Section A4.9) includes a site water balance demonstrating that all tailings water can be contained within the tailings storage facility and that there will be no operational release of tailings water to surface water. This linkage was considered to be invalid.

Sewage effluent will be released from the sewage treatment plant at the construction camp. This linkage was considered to be valid. Sewage effluent from the sewage treatment plant at the processing plant will be released to the process water circuit. This linkage was considered to be invalid.

The mine pit will be dewatered by controlled pumping of groundwater. Required extraction volumes are predicted to be greater than what can be used by the processing plant. The excess water will be released to nearby watercourses. The linkage between mine pit dewatering and surface water quality was considered to be valid.

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. This linkage was assumed to be valid.

Assessment Methods

Changes in Groundwater Flow

The Kasana and Sokalwela rivers are predicted to dry up in the dry season during operation (once pit dewatering begins in Year 8) if pit dewatering water is not used to replace flows (Section C2.11). Only the Kasana River is used by villagers as a water source. The effect of changes in groundwater flow was evaluated by comparing the quality of water in the local watercourses to water quality of the springs in the headwaters of the watercourses that could experience changes in flows to surface waters.

Changes in Groundwater Quality

Groundwater Model Description

A simple groundwater transport model was developed to assess transport of constituents from the tailings management facility, waste rock facilities, ore stockpiles and the pit lake to receiving watercourses. The model was used to predict mass loadings of constituents to the watercourses over time. The groundwater transport model includes attenuation, which is retardation of transport of substances due to adsorption to particles along the groundwater pathway. A detailed description of the model is provided in Appendix C2.12-I.

Input groundwater quality data for the pit lake, waste rock facility, ore stockpiles and the tailings pond seepages are provided in the mine waste characterization study (Appendix B2.3-I). The water quality assessments for the waste rock storage facility and the ore stockpiles included water quality predictions that account for geochemical control mechanisms, such as mineral precipitation, commonly observed at mining sites, as described in Appendix B2.3-I.

Seepage water from the tailings storage facility, waste rock storage facilities and ore stockpiles was assumed to enter the small springs in the headwaters of the Kasana River, while seepage from the pit lake was assumed to enter both the Kasana River and the Dipeta River. A range of groundwater flow scenarios, as described in the hydrogeology impact assessment (Section C2.10), was considered. As a conservative assumption, the highest flow to each watercourse was used in the groundwater transport modeling.

The following assumptions are inherent in the groundwater transport model method:

- Flow is effectively one-dimensional between the source and the point of entry to the stream. All flow from the tailings storage facility, waste rock storage facilities and ore stockpiles enter the small springs in the headwaters of the Kasana River. Flow from the pit lake enters into the headwaters of the Dipeta and Kasana rivers. These conservative assumptions were made in the absence of detailed groundwater transport modeling.
- The groundwater regime can be represented as a porous medium.
- Groundwater flow is steady and uniform along the flowpath.
- Reactions along the flowpath are reversible and can be adequately represented by a linear adsorption isotherm.

- Mass fluxes into the receiving streams increase linearly between the time of initial arrival and the time of arrival for constituents from the furthest point from the receiving stream.
- Mass fluxes into the receiving streams change at the time of closure due to reduction in the volumetric flow of seepage from the waste rock facility and ore stockpiles.

Surface Water Model Description

Mass balance models were used to predict changes in water quality caused by changes in the quality of groundwater due to seepages from the tailings storage facility, waste rock storage facilities, ore stockpiles and the pit lake. The mass balance model included worst case predictions based on a low-flow scenario. Base flow of the rivers was calculated using the average groundwater recharge rates provided in the hydrogeology impact assessment (Section C2.10). The loadings were derived from the groundwater transport model one thousand years after closure. The following assumptions were used in the model:

- Watercourses are fully mixed.
- All substances behave conservatively in the surface water.
- Median seasonal concentrations reflect background conditions.

Only the dry season conditions were modeled as this is when the lowest background flow, and hence greatest effects from the groundwater, is predicted to occur.

Scenarios

The effects of changes in groundwater quality were assessed for three different time frames: Short-term (during the life of the mine); long-term (up to one thousand years after closure); and far-future (greater than one thousand years in the future). The short-term and far-future scenarios were assessed qualitatively. The assessment of the long-term scenario was based on the groundwater and surface water models discussed above. The impact analysis was based on the long-term scenario as geologic processes acting on time scales greater than one thousand years lead to large uncertainties in groundwater flows and seepage quality.

Water Quality Parameters Assessed

All water quality parameters for which sufficient data were available were modeled at the mine area. These parameters are listed in Table C2.12-4.

Table C2.12-4 Water Quality Variables Assessed

Group	Water Quality Variables
major ions	calcium, chloride, magnesium, potassium, sodium and sulfate
nutrients	nitrate and nitrite
metals	aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silicon, silver, strontium, thorium, tin, uranium, vanadium and zinc

Boron and thallium were not included in this assessment. They were generally not encountered above the analytical detection limits used in the geochemistry and water quality baseline determinations. However, these analytes will be included in the ground and surface water quality monitoring programs for the project, using lower detection limits. This will assure that any potential impacts to the Kasana, Mofia and/or Dipeta rivers will be assessed.

Comparison to Baseline Values and Guidelines

Predicted concentrations of the assessed parameters in the receiving streams were compared to corresponding baseline values. Changes in predicted concentrations that were less than 10 percent above background concentrations were assumed to have no effect on the water quality even if background concentrations exceed reference guidelines. Predicted concentrations that were greater than 10 percent higher than baseline concentrations were compared to relevant guidelines. The guidelines used are provided in Section A2.7.5.

Changes in Sedimentation and Quality of Runoff during Construction

Risk of contamination of surface and groundwater from spills was evaluated qualitatively, taking into account mitigation measures described in Section C2.11. No quantitative assessment was conducted.

The stormwater management system has been designed not to discharge waste rock runoff to receiving water bodies at a frequency of greater than once every ten years, on average (Section A4.3.7).

Changes in Sedimentation and Quality of Runoff during 1 in 10 Year Storm Event

Runoff Water Quality Model Description

For the purposes of this assessment this was assumed to be in the 1 in 10 year 24-hour rain event. During these events, the collection ponds for the waste rock facilities and ores stockpiles are predicted to overflow and the runoff waters will be released into the surrounding environment. A mass balance model was used to predict the effects of these releases on the Kasana and Mofia Rivers. In the mine

waste characterization study (Appendix B2.3-I) the water quality was predicted for the runoff from the waste rock storage facilities and the ore stockpiles. The water quality assessments for the waste rock storage facility and the ore stockpiles included water quality predictions that account for geochemical control mechanisms, such as mineral precipitation, commonly observed at mining sites, as described in Appendix B2.3-I.

Modeling assumptions include:

- Watercourses are fully mixed.
- All substances behave conservatively in the surface water.
- The flows over waste rock and natural land are proportional to the respective surface areas during the event.
- Median wet season concentrations reflect background conditions during storm events.

Water Quality Parameters Assessed

The same parameters that were assessed to evaluate the changes in groundwater quality also were used to evaluate changes in the quality of storm water runoff.

Comparison to Baseline Values and Guidelines

Maximum concentrations predicted for the 1 in 10 year storm runoff events were compared to corresponding baseline values. Changes in predicted concentrations that were less than ten percent above background concentrations were assumed to have no effect on the water quality even if background concentrations exceed reference guidelines. Predicted concentrations that were greater than ten percent higher than baseline concentrations were compared to relevant guidelines. For the storm runoff events, only the ambient acute guideline is relevant because these events are very infrequent and have a short time span (1 day in 10 years). The guidelines used are provided in Section A2.7.5.

Liquid Effluents

Sewage Effluents from the Construction Camp/Permanent Village

A mass balance model was used to predict changes in water quality due to release of sewage effluent from the construction camp/permanent village. Sewage effluent was assumed to enter the Kabomboy River. Predicted flows are provided in the surface water hydrology impact assessment (Section C2.11). Water quality for the receiving streams is provided in the water and sediment quality baseline report (Section B2.12). Modeled parameters include ammonia, phosphorus and

biochemical oxygen demand. Treated sewage effluent chemistry is discussed in Section A4.7.1.4.

The following assumptions were used in the model:

- The Kabomboy River is fully mixed.
- All substances behave conservatively in the surface water.
- Median seasonal concentrations reflect background conditions.

Mine Pit Dewatering

The Kasana and Sokawela rivers are predicted to dry up in the dry season during operation if pit dewatering water is not used to replace flows. The effect of replacing water in the surface waters with dewatering water was evaluated by comparing the quality of river water to the water quality of the springs in the headwaters of the rivers. It was assumed that the current springs are derived from groundwater with the same source as the future dewatering wells.

Spills

Impact analysis of contamination of surface and groundwater from spills was evaluated qualitatively, taking into account mitigation measures described in Section C2.11. No assessment was conducted.

Mitigation

Full details of the mitigation proposed is provided in Section D3.1.5.

Changes in Sedimentation and Quality of Runoff

Construction

Protection of the water quality will be accomplished during construction through the use of best management practices (BMP) that are widely accepted to reduce effects of construction. Runoff water will be diverted away from haul roads and other disturbed areas. Stream crossings will be constructed in a way to minimize sedimentation. Technologies for reducing the energy force of runoff water, such as installation of diversion channels, sedimentation ponds, rock filters or plastic water dams, will be selectively implemented so that runoff does not carry significant sediment from disturbed areas.

Operation

Mitigation measures implemented for operation are described in the surface water hydrology linkage analysis (Section C2.11). These measures include:

- Use of diversion ditches and berms to reduce the amount of surface water entering the mining and process areas.
- Incorporating potentially contaminated storm water into the process water circuit.
- Provision of potable groundwater to residents of Mwanga Muteba if impact predictions or monitoring determines that guidelines will be/ are being exceeded.

Closure

Mitigation measures implemented for closure are described in the surface water hydrology linkage analysis (Section C2.11). Mitigation measures include a reclamation landscape with sustainable drainage and vegetation cover to be established at closure. The closure landscape will have slopes and drainage channels that will:

- Minimize erosion.
- Minimize transport of soil material into downstream receiving waters.
- Minimize contact of runoff with mine or waste material.

Spills

Fuel and oil tanks will be placed within secondary lined containment cells to contain spills in the case of tank failure. Equipment maintenance areas will be located away from surface waters and bermed to prevent runoff of equipment fluids. Dedicated storage and handling areas for waste materials will be used. A waste management plan and an emergency response plan will be part of an environmental and social management system (Volume D).

Results

Changes in Groundwater Flow and Release Water from Mine Pit Dewatering

The groundwater assessment indicates that some springs could dry up in the dry season in the Kasana and Sokawela catchments due to mine pit dewatering. Drying up of springs will affect baseflow in the catchments. Baseflow is predicted to be completely eliminated for portions of each catchment without mitigation. Mine pit dewatering water will be used to mitigate the effects of decreased natural groundwater inputs. Baseflow is predicted to return to near

baseline conditions after mine pit dewatering ceases and the groundwater regime returns to a state of equilibrium (Section C2.10).

The spring water in the headwaters of the catchment has major ions and total dissolved solids concentrations within the range of concentrations in surface waters. Nitrogen parameters as well as barium, iron and strontium were higher in the springs than in surface water; however, none of these parameters exceed guidelines in the spring waters. Therefore, there is no expected degradation in surface water quality as a result of changes in groundwater flow or release of water from pit dewatering.

Changes in Groundwater Quality

Short-term Effects (during the life of the mine)

The groundwater model shows that with the exception of some of the major ions, contaminants in seepage waters do not reach the Kasana River until after closure. Thus there is no expected decline in water quality in the short term as a result of changes in groundwater quality.

Long-term Effects (up to one thousand years after closure)

Table C2.12-5 provides the predicted concentrations in the Kasana, Mofia and Dipeta rivers one thousand years after closure. Concentrations are the maximum predicted over the first 1,000 years. The three assessment nodes (potential environmental compliance points) are shown in Figure C2.12-2. The table includes the background water quality in each river as well as the maximum and minimum concentrations predicted to occur in each river.

Concentrations of major ions in seepage waters entering the receiving streams are not expected to change over the examined timeframe (Appendix C2.12-I). Maximum predicted concentrations of chloride, potassium, sodium and sulfate are greater than the background concentrations in all three rivers but the maximum concentrations are not predicted to exceed any guidelines.

One thousand years after closure, maximum predicted concentrations of several metals are predicted to exceed background concentrations by more than 10 percent in at least one of the rivers. However, none of the parameters are predicted to exceed any of the reference water quality guidelines.

Table C2.12-5 Background and Predicted Concentrations in the Kasana, Mofia and Dipeta Rivers in the Dry Season 1,000 Years after Closure

Parameter	Units	Kasana Dry Season			Mofia Dry Season			Dipeta Dry Season		
		Background Concentrations (2006)[a]	Predicted Concentrations[f]		Background Concentrations (2006)[a]	Predicted Concentrations[f]		Background Concentrations (2006)[a]	Predicted Concentrations[f]	
			Minimum	Maximum		Minimum	Maximum		Minimum	Maximum
Nutrients										
nitrate + nitrite (as nitrogen)	mg/L	0.7	**0.7**	**0.7**	0.2	0.2	0.2	0.6	0.6	0.6
total phosphate	mg/L	0.6	0.6	0.6	0.05	0.05	0.05	1.1	1	1
Major Ions										
calcium	mg/L	58	63	*67*	48	48	49	54	55	57
chloride	mg/L	0.1	3	*98*	0.3	*1*	*7*	0.3	*1*	*14*
magnesium	mg/L	69	69	69	38	38	38	56	56	56
potassium	mg/L	2	7	*120*	2	2	*9*	3	3	*57*
sodium	mg/L	3	3	*36*	5	5	*7*	2	2	*3*
sulfate	mg/L	41	47	*230*	11	11	*23*	39	39	*53*
Metals[d]										
aluminum	µg/L	4	4	4	3	3	3	5	5	5
antimony	µg/L	0.5[e]	0.5	*0.8*	0.5[e]	0.5	0.5	0.5[e]	0.5	*0.7*
arsenic	µg/L	0.3	0.3	*0.4*	1	1	1	0.4	0.4	0.4
barium	µg/L	161	161	161	252	252	252	165	170	170
beryllium	µg/L	0.5[e]	0.5	0.5	0.5[e]	0.5	0.5	0.5[e]	0.5	0.5
cadmium	µg/L	0.05[e]	0.05	0.05	0.05[e]	0.05	0.05	0.05[e]	0.05	0.05
chromium[b]	µg/L	0.5[e]	0.5	0.5	0.5[e]	0.5	0.5	0.5[e]	0.5	0.5
cobalt	µg/L	1[e]	1	*17*	1[e]	1	*2*	7	7	7
copper	µg/L	1[e]	1	1	1[e]	1	1	3	3	3
iron	µg/L	5	5	5	4	4	4	4	4	4
lead	µg/L	0.5[e]	0.5	0.5	0.5[e]	0.5	0.5	0.5[e]	0.5	0.5
manganese	µg/L	12	12	*16*	**30[P]**	**30[P]**	**30[P]**	6	6	6
mercury	µg/L	0.05[e]	0.05	0.05	0.05[e]	0.05	0.05	0.05[e]	0.05	0.05
molybdenum	µg/L	0.5[e]	0.5	*0.7*	0.5[e]	0.5	0.5	0.5[e]	0.5	0.5
nickel	µg/L	3	3	3	2	2	2	3	3	3
selenium	µg/L	0.5[e]	0.5	1	1	1	1	0.5[e]	0.5	0.5

Table C2.12-5 Background and Predicted Concentrations in the Kasana, Mofia and Dipeta Rivers in the Dry Season one thousand Years after Closure (continued)

Parameter	Units	Kasana Dry Season			Mofia Dry Season			Dipeta Dry Season		
		Background Concentrations (2006)[a]	Predicted Concentrations[f]		Background Concentrations (2006)[a]	Predicted Concentrations[f]		Background Concentrations (2006)[a]	Predicted Concentrations[f]	
			Minimum	Maximum		Minimum	Maximum		Minimum	Maximum
silver	µg/L	0.5[e]	0.5	*0.8*	0.5[e]	0.5	0.5	0.5[e]	0.5	0.7
strontium	µg/L	566	570	570	220	220	220	360	360	360
tin	µg/L	0.5[e]	*1*	*1*	0.5[e]	0.5	0.5	0.5[e]	0.5	0.5
uranium	µg/L	0.4	0.4	0.4	0.3	0.3	0.3	1	1	1
vanadium	µg/L	2	2	2	1	1	1	1	1	1
zinc	µg/L	3	3	3	5	5	5	4	4	4

[a] Background data is based on data provided in Table B2.12-7.

[b] Flow values were calculated assuming an average flow value of 175 mm/yr over the catchment area.

[c] Predicted pH, temperature and hardness were assumed to be equal to baseline median values and were used in the calculation of guidelines.

[d] Values based on dissolved metals concentrations as no data for total metals were available.

[e] The median concentration was below the detection limit and half of the detection limit was used to represent the background concentration.

[f] Values calculated by adding the groundwater loadings derived in Appendix C2.12-I to the background loadings.

Bolded concentrations are higher than relevant water quality guidelines. Italicized values are higher than background by more than 10 percent.

D = concentration higher than the most stringent drinking water guideline.

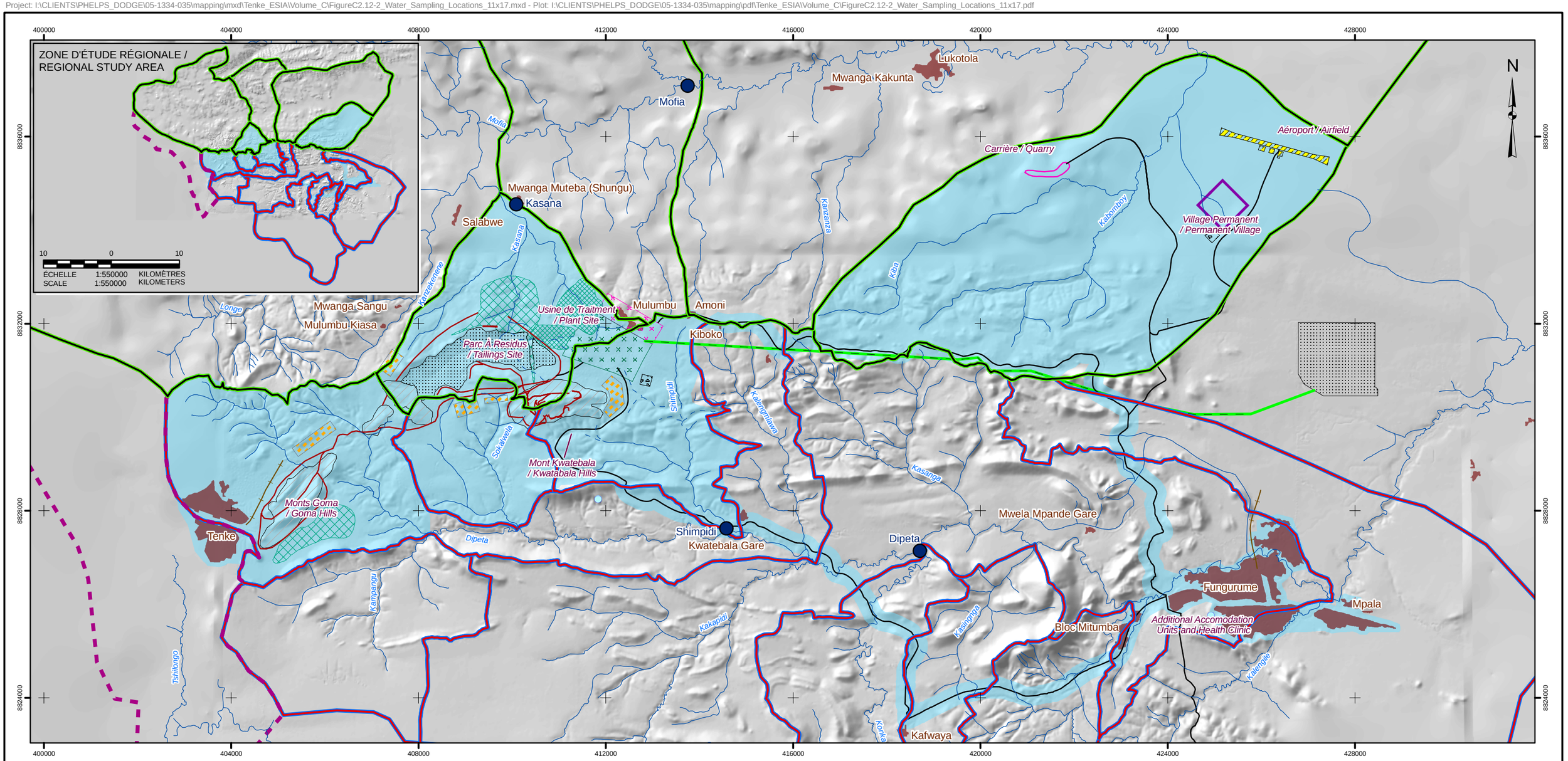
P = concentration higher than the South Africa Guidelines for plant health.

L = concentration higher than the South Africa Guidelines for livestock.

A = concentration higher than the relevant US EPA acute aquatic life guideline.

C = concentration higher than the relevant US EPA chronic aquatic life guideline.

- = no data / no guideline.



LÉGENDE / LEGEND

- NOEUD D'ÉVALUATION / ASSESSMENT NODE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER

BASSINS VERSANTS / CATCHEMENT

- DIPETA
- MOFIA
- TSHILONGO
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- ZONE D'ÈTUDE LOCALE / LOCAL STUDY AREA

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE / MINE PIT
- LIMITES DE LA FUTURE IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3
ÉCHELLE 1:80000 KILOMÈTRES
SCALE 1:80000 KILOMETERS

PROJET / PROJECT
PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE
NOEUD D'ÉVALUATION POUR L'ÉTUDE HYDROLOGIQUE / ASSESSMENT NODES FOR WATER QUALITY

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	TR	15 May 2006		
GIS / SIG	KL	04 Jan. 2007		
VÉRIFIÉ / CHECK	MR	24 Oct. 2006		
APPROUVÉ REVIEW	MR	24 Oct. 2006		

FIGURE: C2.12-2

Far Future Effects

On very long time scales, attenuation is not expected to affect loading for many metals. Therefore, the groundwater model predicts that the concentration of the metals in the groundwater entering the streams is the same as than in the seepages. However, on very long timescales many of the assumptions in the groundwater model are not valid. Geological processes acting on these time scales are likely to dramatically change the groundwater dynamics of the region and prediction of the influence of the groundwater on the local streams is not practical. Additionally, the quality of the seepage from waste rock facilities and ore stockpiles would be expected to change over this timeframe.

Changes in Runoff Water Quality during Storm Events

Tables C2.12-6 and C2.12-7 provide predicted concentrations in the Kasana and Mofia rivers during the 1 in 10 year rainfall events. The storm water handling system has been designed to contain all water up to the rainfall conditions represented by this design criteria. Therefore, this is the only condition under which a reasonably predictable discharge of "contact" storm waters may occur. Both tables include:

- World Bank and DRC effluent standards.
- Background water quality in the river for the 2006 wet season.
- Predicted runoff quality from the wasterock storage facility and ore stockpile.
- Predicted concentrations in the river resulting from the storm water release.

The two assessment nodes (potential human and environmental compliance points) are shown in Figure C2.12-2.

In the Kasana and Mofia rivers, the maximum predicted concentrations of some constituents are predicted to exceed background concentrations in the river by greater than 10 percent. None of the relevant reference guidelines are exceeded by these constituents.

All of the predicted concentrations in the Kasana and Mofia rivers are below acute ambient guidelines as described in Section A2.7. Other ambient guidelines are not relevant to a short-term, one day in ten year release. Thus, the temporary exceedances of the plant health, human health and chronic aquatic guidelines would not have an effect on the water uses of the Kasana or Mofia rivers.

Table C2.12-6 Model Inputs and Predicted Maximum Concentrations in the Kasana River during 1 in 10 Year Runoff Events

Kasana River Runoff Model - Wet Season							
Parameter	Units	World Bank Effluent Standards	DRC Effluent Standards	Background Concentration (2006)[a]	Input Concentrations[f]		Predicted Concentration
					Maximum Wasterock Runoff	Maximum Ore Stockpile Runoff	
Nutrients							
nitrate + nitrite (as nitrogen)	mg/L	-	-	0.2	13	9	*4*
total phosphate	mg/L	-	-	1	0.3	0.03	1
Major Ions							
calcium	mg/L	-	-	58	18	1	42
chloride	mg/L	-	-	4	10	10[g]	6
magnesium	mg/L	-	-	66	15	0	47
potassium	mg/L	-	-	2	11	3	*4*
sodium	mg/L	-	-	4	3	2	4
sulfate	mg/L	-	-	41	56	7	39
Metals[d]							
aluminum	µg/L	-	-	5[e]	340	13	*69*
antimony	µg/L	-	-	5[e]	20	1	*7*
arsenic	µg/L	100	400	10[e]	7	1	8
barium	µg/L	-	-	150	53	1	110
beryllium	µg/L	-	-	1[e]	1	1	1
boron	µg/L	-	-	3[e]	20	20	*9*
cadmium	µg/L	100	-	0.5[e]	2	1	*0.9*
chromium	µg/L	50	-	2[e]	7	1	2
cobalt	µg/L	-	-	1[e]	380	150	*94*
copper	µg/L	300	1500	1[e]	16	170[A]	*30*
iron	µg/L	2000	6000	0.5[e]	1	1	*1*
lead	µg/L	100	500	5[e]	6	1	5
manganese	µg/L	-	-	20	260	3	*63*
mercury	µg/L	2	2	0.5[h]	1	1	*1*
molybdenum	µg/L	-	-	0.5[e]	1[g]	1	*1*
nickel	µg/L	500	1000	2[e]	16	1	*4*
selenium	µg/L	-	-	10[e]	10	1	9
silver	µg/L	-	-	2[e]	3	1	2
strontium	µg/L	-	-	220	1[g]	1	140
tin	µg/L	-	-	10[e]	1[g]	1	7
uranium	µg/L	-	-	2[e]	1[g]	1	2
vanadium	µg/L	-	-	1[e]	1[g]	1	1
zinc	µg/L	1000	10000	3[e]	150	5	*29*

[a] Background data is based on data provided in Table B2.12-5.
[b] Flow values were calculated assuming the 95th percentile of the wet season flow (Section B2.11) and that the flows over waste rock and natural land are proportional to the respective surface areas during the event.
[c] Predicted pH, temperature and hardness were assumed to be equal to baseline median values and were used in the calculation of guidelines.
[d] Values based on dissolved metals concentrations as no data for total metals were available.
[e] The median concentration was below the detection limit and half of the detection limit was used to represent the background concentration.
[f] Values from the Mine Water Characterization study (Appendix B2.3-I).
[g] No value was predicted so value assumed to be equal to the ore/waste rock runoff.
[h] This is the total mercury concentration.

Bolded concentrations are higher than relevant water quality guidelines. Italicized values are higher than background by more than 10 percent.
A = concentration higher than the relevant US EPA acute aquatic life guideline.
E = concentration higher than the relevant DRC effluent standards.
W = concentration higher than the World Bank Effluent Standards.
- = no data / no guideline.

Table C2.12-7 Model Inputs and Predicted Maximum Concentrations in the Mofia River during 1 in 10 Year Runoff Events

Mofia River Runoff Model - Wet Season							
Parameter	**Units**	**World Bank Effluent Standards**	**DRC Effluent Standards**	**Background Concentration (2006)[a]**	**Input Concentrations[f]**		**Predicted Concentration**
					Maximum Wasterock Runoff	**Maximum Ore Stockpile Runoff**	
Nutrients							
nitrate + nitrite (as nitrogen)	mg/L	-	-	0.1	13	9	*0.2*
total phosphate	mg/L	-	-	0.1	0.3	0.03	0.1
Major Ions							
calcium	mg/L	-	-	22	18	1	22
chloride	mg/L	-	-	6	10	10[g]	6
magnesium	mg/L	-	-	15	15	0	15
potassium	mg/L	-	-	2	11	3	2
sodium	mg/L	-	-	4	3	2	4
sulfate	mg/L	-	-	6	56	7	6
Metals[d]							
aluminum	µg/L	-	-	5[e]	350	13	*7*
antimony	µg/L	-	-	5[e]	20	1	5
arsenic	µg/L	100	400	10[e]	8	1	10
barium	µg/L	-	-	50	50	1	50
beryllium	µg/L	-	-	1[e]	1[e]	1	1
boron	µg/L	-	-	3[e]	20	20	3
cadmium	µg/L	100	-	0.5[e]	2	1	0.5
chromium	µg/L	50	-	1.5[e]	7	1	*2*
cobalt	µg/L	-	-	1[e]	380	150	*4*
copper	µg/L	300	1500	1[e]	16	**170[A]**	*2*
iron	µg/L	2000	6000	0.5[e]	1	1	*1*
lead	µg/L	100	500	5[e]	6	1	5
manganese	µg/L	-	-	2	260	3	*4*
mercury	µg/L	2	2	0.5[h]	1	1	0.5
molybdenum	µg/L	-	-	0.5[e]	1[g]	1	0.5
nickel	µg/L	500	1000	1.5[e]	16	1	*2*
selenium	µg/L	-	-	15[e]	10	1	15
silver	µg/L	-	-	2[e]	3	1	2
strontium	µg/L	-	-	30	1[g]	1	30
tin	µg/L	-	-	10[e]	1[g]	1	10
uranium	µg/L	-	-	2[e]	1[g]	1	2
vanadium	µg/L	-	-	9	1[g]	1	9
zinc	µg/L	1000	10000	2.5[e]	150	5	*3*

[a] Background data is based on data provided in Table B2.12-5.
[b] Flow values were calculated assuming the 95th percentile of the wet season flow (Section B2.11) and that the flows over waste rock and natural land are proportional to the respective surface areas during the event.
[c] Predicted pH, temperature and hardness were assumed to be equal to baseline median values and were used in the calculation of guidelines.
[d] Values based on dissolved metals concentrations as no data for total metals were available.
[e] The median concentration was below the detection limit and half of the detection limit was used to represent the background concentration.
[f] Values from the Mine Water Characterization study (Appendix B2.3-I).
[g] No value was predicted so value assumed to be equal to the ore/waste rock runoff.
[h] This is the total mercury concentration.

Bolded concentrations are higher than relevant water quality guidelines. Italicized values are higher than background by more than 10 percent.
A = concentration higher than the relevant US EPA acute aquatic life guideline.
E = concentration higher than the relevant DRC effluent standards.
W = concentration higher than the World Bank Effluent Standards.
- = no data / no guideline

None of the runoff concentrations from the waste rock facility or the ore stockpiles are predicted to exceed either the World Bank or DRC effluent standards. Maximum copper concentrations in the runoff from the ore stockpile could exceed the US EPA acute guidelines for the protection of aquatic life but this effect is diluted in the Kasana and Mofia rivers.

Release of Sewage Effluents from the Construction Camp

A sewage treatment plant will be installed to treat waste from individual dwelling units, communal buildings and the kitchen and mess. The sewage treatment plant will produce both solid and liquid waste products. The solids (i.e., sludge) will either be composted and, provided adequate sterilization is achieved, used as a soil amendment, or will be disposed of in a landfill. Water use per person was assumed to range from 80 to 200 liters per day and the peak construction camp occupancy will be about 2,500 people (including workers and their families). Where households are connected to piped water supplies, wastewater is generated at a rate of 35 to 200 liters per person per day, depending on the water supply service level, climate and water availability (Helmer and Hespanhol 1997). In developing countries, wastewater production rarely exceeds 100 liters per day whereas in the United States, wastewater production can exceed 200 liters per day (Winblad and Simpson-Hebert 2004; Crites and Tchobanoglous 1998).

Sewage effluent characteristics and predicted concentrations in the Kabomboy River are shown in Table C2.12-8 and are provided in Section A4.7.1.4 for BOD, TSS and ammonia. Nitrate + nitrite and phosphate concentrations are specifications commonly used by the World Health Organization to represent concentrations in treated municipal wastewater (see for example WHO 2006). No guideline exceedances are predicted to result from the release of treated sewage effluent to the river. Total suspended solids concentrations are predicted to be lower than background concentrations. Small increases in biological oxygen demand, nitrate + nitrite and total phosphate concentrations are predicted, but predicted concentrations are within the range of concentrations observed in surface waters in the area as shown in Section B2.12.

Impact Analysis

Table C2.12-9 presents a summary of the residual impacts for key question WQ-1.

Table C2.12-8 Sewage Effluent Characteristics and Predicted Concentrations in the Kabomboy River

Parameter	Units	Background Concentration in the Kabomboy River		Sewage Treatment Plant		Predicted Concentration in the Kabomboy River			
						Dry Season		Wet season	
		Dry	Wet	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
flow	m^3/s	0.07	0.22	0.0058	0.0023	0.076	0.072	0.23	0.22
ammonia (total) (as nitrogen)	mg/L	0.05	0.05	10	10	0.8	0.4	0.3	0.1
nitrate + nitrite (as nitrogen)	mg/L	0.05	0.2	15	15	1.2	0.5	0.4	0.2
total phosphate	mg/L	0.05	0.05	3	3	0.3	0.1	0.1	0.05
total suspended solid	mg/L	206	4	30	30	193	200	201	65
biological oxygen demand	mg/L	0.6	1.3	20	20	2.1	1.2	1.1	0.4

mg/L = milligram per liter.

Table C2.12-9 Residual Impact Classification for WQ-1

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question-WQ-1: What effect will the project have on water quality in local watercourses?						
Pathway: Changes in groundwater quality						
negative	low	local	long-term	no	low	low
Pathway: Changes in sedimentation and quality of runoff during construction						
negative	negligible	local	short-term	yes	medium	negligible
Pathway: Changes in sedimentation and quality of runoff during storm events						
negative	low	local	short-term	yes	low	low
Pathway: Sewage effluents						
Negative	negligible	local	long-term	yes	high	negligible
Pathway: Changes in groundwater flow and release from mine pit dewatering						
negative	negligible	local	long-term	yes	high	negligible
Pathway: Spills						
negative	negligible	local	short-term	yes	low	negligible

The magnitude of the residual effects from changes in groundwater quality is low. Maximum predicted concentrations of several major ions, nutrients and metals are predicted to exceed background concentrations in the Kasana, Mofia and Dipeta rivers due to seepage from the ore stockpiles, tailings pond, pit lake and waste rock storage facilities. None of these predicted increases resulted in exceedances of reference guidelines and therefore, the magnitude was classified as low. The effects are negative in direction and local in geographic extent because effects are limited to the catchments in the vicinity of the project,

particularly the Kasana catchment. The duration is classified as long-term, corresponding to the life of the project and far into the future. The frequency of the predicted effects is classified as low because background concentration exceedances would be expected only under conditions of very low river flows. The effects are considered irreversible as seepage cannot easily be recaptured. The environmental consequence of the predicted effects is low.

The magnitude of the residual effects from changes in sedimentation and quality of runoff during construction is negligible because universally accepted BMPs will be used during construction. The effects are negative in direction and local in geographic extent. The duration is classified as short-term. The frequency of the predicted effects is classified as low and the effects are considered reversible. The environmental consequence of the predicted effects is negligible.

The magnitude of the residual effects from changes in sedimentation and quality of runoff during the 1 in 10 year storm events is low. While the maximum predicted concentrations of several parameters are predicted to exceed background concentrations, no relevant guidelines are predicted to be exceeded as a result of these changes and therefore, the magnitude was classified as low. The effects are negative in direction and local in geographic extent. The duration is classified as short-term as these exceedances will only occur during the flooding events while the mine is in operation. The frequency of the predicted effects is classified as low and the effects are considered reversible. The environmental consequence of the predicted effects is low as the predicted concentrations in the Kasana River are below acute ambient guidelines as described in Section A2.7. Other ambient guidelines are not relevant to short-term infrequent releases

The magnitude of the residual effects from treated sewage release is negligible because no guideline exceedances are predicted and predicted concentrations are within the range of variation in the surface waters in the area. The effects are negative in direction and local in geographic extent. The duration is classified as long-term, corresponding to the life of the project. The frequency of the predicted effects is classified as high (continuous) and the effects are considered reversible. The environmental consequence of the predicted effects is negligible.

The magnitude of the residual effects from changes in groundwater flow and release of mine pit dewatering water is negligible because pit dewatering water is expected to have similar quality to the springs that naturally feed the headwaters of the streams. The effects are negative in direction and local in geographic extent because effects are limited to the catchments in the vicinity of the project, particularly the Kasana and Sokalwela catchments. The duration is classified as long-term, corresponding to the life of the project. The frequency of the predicted

effects is classified as high (continuous) and the effects are considered reversible. The environmental consequence of the predicted effects is negligible.

The magnitude of the residual effects from spills is negligible because safety measures will be put in place to prevent spills from reaching surface water and groundwater. The effects are negative in direction and local in geographic extent. The duration is classified as short-term. The frequency of the predicted effects is classified as low and the effects are considered reversible. The environmental consequence of the predicted effects is negligible.

Prediction Confidence

Impact predictions regarding water quality are generally subject to a moderate uncertainty; however, conservative assumptions were made to address the uncertainty. The major sources of uncertainty include those associated with tailings, ore stockpile and waste rock seepage quality and groundwater flow patterns, as well as the water quality of the pit lake. These sources of uncertainty are being addressed through further data collection as described in Section C2-10 and Section D3.

Monitoring

The surface water resources action plan (Section D3.1.5) has been designed to confirm impact predictions on surface water and sediment quality. Waste rock and ore stockpile toe seepages and runoff, and the pit lake and tailings pond will be monitored to verify that concentrations of constituents are below the worst-case predictions provided in this assessment. This program will also identify any unanticipated effects (Section D3.1.5). The purpose of identifying unanticipated effects and their cause is to adaptively manage or mitigate these impacts quickly and effectively.

C2.12.3.5 Key Question WQ-2

Key question WQ-2 is: What effect will the project have on sediment quality in local watercourses?

Linkage Evaluation

The mine development and operation 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 (i.e., immobilization through bonding with solid material) of these substances to sediment and result in changes in sediment quality. If unmitigated, increased sediment runoff could contribute to

changes in substance concentrations in bottom sediments of receiving watercourses and water bodies.

Because the water quality constituents predicted to exceed background concentrations are not associated with sediments and there was no linkage between sediment runoff and water quality, the linkage between mine activities and sediment quality was considered to be invalid.

Monitoring

The surface water resources action plan (Section D3.1.5) has been designed to confirm impact predictions on surface water and sediment quality. This program will also identify any unanticipated effects. The purpose of identifying unanticipated effects and their cause is to adaptively manage or mitigate these impacts quickly and effectively.

C2.12.3.6 Key Question WQ-3

Key question WQ-3 is: What are the predicted water quality characteristics of the pit lake?

Linkage Evaluation

Effects of seepage from the pit lake on local watercourses were assessed in Section C2.12.3.4. The pit lake could potentially be a new waterbody, which could be used for supporting aquatic life or other purposes; however, initial predictions of the pit lake quality indicates that concentrations of metals and major ions could be high and that there is a potential that the water would not support aquatic life or other uses (Appendix B2.3-I). Issues associated with mitigating the potential effects of the pit lake on human health are addressed in the reclamation and closure plan (Section D5).

C2.12.3.7 Key Question WQ-4

Key question WQ-4 is: How can the project have a positive effect on water and sediment quality?

Linkage Evaluation

The project could have a positive effect on water and sediment quality in streams by improving the water quality in surface runoff. Currently surface water runoff is affected by disturbance caused from unauthorized artisanal mining. The

disturbed areas would become part of the current mine and surface water runoff would be contained and used within the process water circuit.

The project could have a positive effect on diseases associated with poor water quality and sanitation by implementing a sanitation and hygiene education program as outlined by WHO (WHO 2005), which could mitigate the current effects of poor water quality and sanitation. The program guide for sanitation and hygiene promotion lays out a process for long-term change based on proven approaches. The hygiene promotion component of the approach includes:

- Communication.
- Social mobilization.
- Community participation.
- Social marketing.
- Advocacy.

Other components of the approach include access to a clean environment. The DRC has less than 50 percent water supply coverage and less than 25 percent sanitation coverage. Provision of adequate sanitation services, safe water supply, and hygiene education represents an effective health intervention that reduces the mortality caused by diarrheal disease by an average of 65 percent and the related morbidity by 26 percent. Hygiene education is one of the primary constraints in implementing sanitation programs and it has been recognized that community participation and education are critical components of a successful sanitation and hygiene program. Education has been identified as the most important factor in improving sanitation and hygiene and preventing associated diseases (WHO and UNICEF 2000).

Assessment Methods

The impact analysis was carried out using professional judgment concerning the potential benefits of sustainable project mitigation measures. No formal assessment was undertaken.

Impact Analysis

Table C2.12-10 presents a summary of the residual impacts for sustainability effects.

Table C2.12-10 Sustainability Effects for WQ-4

Magnitude	Span or Reach	Duration	Probability of Success	Consequence
WQ-4 How can the project have a positive effect on water and sediment quality?				
Improved surface runoff quality				
uncertain	entire community	long-term	high	uncertain
Implement sanitation and hygiene program				
high	entire community	long-term	high	high

The magnitude of the residual effects from improved runoff quality is uncertain because sufficient monitoring has not been undertaken to determine the contribution of runoff from unauthorized artisanal mining to current water quality in the catchment. There is some indication that concentrations of copper are higher now than they were during the 1997/1998 sampling program. The span is local, because changes would likely only affect the LSA. The duration is long-term because mitigation measures for surface runoff extend beyond the life of the project. The probability of success is high because mitigation measures will be designed as part of the mine plan to collect surface water runoff from the mine area and to reclaim the landscape at closure. The consequence is uncertain due to uncertainty in the magnitude of the potential effects.

The magnitude of residual effects from a sanitation and hygiene project is high. Studies have demonstrated that similar programs have result in measurable reductions in disease (WHO 2005). The reach is the entire community because the entire concession will be targeted by the program and the duration is long-term because the program is expected to have lasting effects. The probability of success is high because similar programs have been implemented with success and form an example of how to implement a successful program. The consequence is high.

Prediction Confidence

The prediction confidence is high because mitigation measures for surface runoff and program requirements for a sanitation and hygiene program are well understood. However, uncertainty in the magnitude of effects of current informal mining means that the potential improvements to surface water due to surface water management at the mine are unknown.

C2.12.4 Cumulative Effects Assessment

The cumulative effects assessment addresses two cases:

- Processing of ore from the Goma and Fwaulu pits at the Kwatebala site.
- Expanded production of from 115,000 tonnes of copper per year to 400,000 tonnes per year.

Linkage Evaluation

Should the project be expanded from a production of 115,000 tonnes of copper per year to 400,000 tonnes per year, the physical extent of water rock facilities, tailings storage facilities, and other mine-related facilities would increase. Processing of additional ore at the Kwatebala site would result in generation of more wasterock and larger ore stockpiles in the Kasana catchment. All linkages considered valid for the impact assessment are also valid for the cumulative effects assessment.

Assessment Methods

Detailed plans for the additional development of the project to expand to 400,000 tonnes per year are not yet available. No formal assessment was conducted but the impact analysis was conducted qualitatively based on the assessment results for the 115,000 tonnes of copper per year scenario presented in the impact assessment. Likewise, a qualitative assessment was undertaken to evaluate inclusion of ore and wasterock for the Goma and Fuwala Pits in production at the Kwatebala plant site in the Kasana catchment. This assessment assumes the following:

- That the mineralogy of the ore bodies for the expansion project is similar to that represented for the Kwatebala pit described in Section C2.12.3 (i.e., mining of oxide ore only). It is assumed that no sulfide or transitional ores are mined.
- That the Kasana and Dipeta catchments are representative of other catchments in the concession.

As a component of the qualitative assessment, Table C2.12-5, predicted concentrations in the Kasana, Mofia and Dipeta rivers, was updated assuming that loadings to the rivers were twice as high as for the Kwatebala pit scenario described in Section C2.12.3 (results of this assessment not presented). The increased loadings qualitatively represent additional waste rock and ore from other pits. Seepage sources contributing to the loadings include the pit lake,

waste rock storage facilities, ore stockpiles and run-of-mine stockpiles. The results of the assessment were similar to the Kwatebala pit scenario in that some constituents were predicted to have concentrations elevated more than 10 percent above background, but no guideline exceedances were predicted as a result of seepages from the mine.

Impact Analysis

Residual effects for changes in sediment quality and runoff during construction, sewage effluents, mine pit dewater and spills are predicted to be negligible because the impact pathways and results of the impact assessment remain valid for a larger scale project (Table C2.12-11).

Table C2.12-11 Residual Impact Classification for $WQ_{(ce)}$-1

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question-$WQ_{(ce)}$-1: What effect will the project have on water quality in local watercourses?						
Pathway: Changes in groundwater quality						
negative	low	local	long-term	no	low	low
Pathway: Changes in sedimentation and quality of runoff during construction						
negative	negligible	local	short-term	yes	medium	negligible
Pathway: Changes in sedimentation and quality of runoff during storm events						
negative	low	local	short-term	yes	low	low
Pathway: Sewage effluents						
negative	negligible	local	long-term	yes	high	negligible
Pathway: Changes in groundwater flow and release from mine pit dewatering						
negative	negligible	local	long-term	yes	high	negligible
Pathway: Spills						
negative	negligible	local	short-term	yes	low	negligible

The magnitude of the residual effects from changes in groundwater quality is low. The ore bodies are distributed throughout the concession and effects in local catchments would likely be similar to those predicted for the Kasana River. Kasana River predictions for additional ore bodies are similar to the Kwatebala only scenario. The effects are negative in direction and local in geographic extent. Effect duration is classified as long-term, corresponding to the life of the project and into the future. The frequency of the predicted effects is classified as low because guideline exceedances would be expected only under conditions of very low river flows. The effects are considered irreversible as seepage cannot easily be recaptured. The environmental consequence of the predicted effects is moderate.

The magnitude of the residual effects from changes in the runoff water quality is also low. Again, the similarity of the ore bodies in the surrounding catchments means that the runoff quality would be similar to those predicted for the Kasana River. If the mine water containment strategies were similar, then release of untreated runoff water during major storm events would have similar effects in the small streams in the surrounding catchments. The effects are local in extent and short term in duration. The effects are considered reversible as they will only last during the flooding event. The environmental consequence of the predicted effects is low as acute ambient guidelines are not likely to be exceeded and other ambient guidelines are not relevant to short-term infrequent releases.

Prediction Confidence

Impact predictions regarding water and sediment quality are generally subject to a low degree of confidence. Information concerning the effects of a larger, 400,000 tonnes per year project is limited, and no formal impact analysis was conducted. Therefore, the prediction confidence in the cumulative effects assessment is low.

Monitoring

Monitoring efforts under the cumulative case will be similar to those proposed for the project case but larger in scale. If this larger project goes ahead, a new environmental assessment with more detailed information will be prepared.

C2.12.5 Conclusions

Residual Impacts

Residual impacts for water quality are provided in Table C2.12-12. No valid linkages were found for sediment quality and therefore no residual impacts are predicted.

The linkages between surface water flow and water quality in surface waters was found to be invalid except for runoff during the 1 in 10 year storm events because the resulting changes in stream flow were small. The magnitude of the changes to the runoff water quality during these events was found to be low as maximum concentrations of constituents exceed background concentrations but not reference guidelines. These events are expected to be short and because no ambient acute guidelines are predicted to be exceeded, the environmental consequences are predicted to be low. Generally conservative assumptions were used for the groundwater and geochemistry modeling. Monitoring will be undertaken to verify that runoff quality is better than that predicted in the impact assessment (Section D3.1.5).

Table C2.12-12 Summary of Residual Impact Classification for Water Quality

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
WQ-1: What effect will the project have on water quality in local springs and watercourses and drinking water?						
Changes in groundwater quality						
negative	low	local	long-term	no	low	low
Changes in runoff water quality during storm events						
negative	low	local	long-term	no	low	low
Other pathways						
negative	negligible	local	short-term	yes	low to high	negligible

The environmental consequences of spills and changes in sedimentation during construction were found to be negligible due to mitigation measures for the project. The mitigation measures include universally accepted best management practices.

The environmental consequences of release of mine pit dewatering water is negligible because pit dewatering is expected to have similar quality to the springs that naturally feed the headwaters of the streams and flows used for mitigation of stream flows are expected to be similar to natural flows.

The environmental consequences of changes surface water quality due to discharge of impacted groundwater are predicted to be low. While concentrations of some parameters may be more than 10 percent higher than background concentrations in the Kasana, Mofia and Dipeta rivers due to seepage from ore stockpiles, tailings pond, pit lake and waste rock storage facility, no relevant guidelines are predicted to be exceeded as a result of these changes and therefore, the magnitude was classified as low. There is a moderate degree of uncertainty associated with these predictions due to uncertainty in groundwater flow patterns. Generally conservative assumptions were used for the groundwater and geochemistry modeling; however, the assumption was also made that certain chemical control mechanisms would operate in the waste rock and ore stockpile seepage. The water quality assessments for the waste rock storage facility and ore stockpile included water quality predictions that account for geochemical control mechanisms, such as mineral precipitation, commonly observed at mining sites, as described in Appendix B2.3-I. Verification of these predictions will be undertaken during the early stages of mining by monitoring toe seepage and runoff from waste rock storage facilities and ores stockpiles (Section D3.1.5).

Sustainability Effects

Table C2.12-13 provides a summary of sustainability effects.

Table C2.12-13 Sustainability Effects for WQ-4

Magnitude	Span or Reach	Duration	Probability of Success	Consequence
WQ-4: How can the project have a positive effect on water and sediment quality?				
Improved surface runoff quality				
uncertain	entire community	long-term	high	uncertain
Implement sanitation and hygiene program				
high	entire community	long-term	high	high

The project could have a positive effect on water and sediment quality in streams by improving the water quality in surface runoff and reducing sedimentation in runoff. Currently surface water runoff is affected by disturbance caused from informal mining. The consequence of improving surface water runoff is uncertain because the quality of current runoff associated with informal mining is not known.

The project could have a positive effect on diseases affected by poor water quality and sanitation by implementing a sanitation and hygiene program as outlined by WHO (2005). The consequence of a sanitation and hygiene project is high because the approach is proven, affects the entire community and magnitude of the effect is high because similar programs have result in measurable reductions in disease.

Cumulative Effects

Table C2.12-14 presents a summary of the residual impacts for cumulative effects. Predicted environmental consequences are similar to the project case.

Table C2.12-14 Summary of Residual Cumulative Impact Classification for Water Quality

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question-$WQ_{(ce)}$-1: What effect will the project have on water quality in local watercourses?						
Changes in groundwater quality						
negative	low	local	long-term	no	low	low
Changes in runoff water quality during storm events						
negative	low	local	long-term	no	low	low
Other pathways						
negative	negligible	local	short-term	yes	low to high	negligible

C2.13 TRAFFIC

C2.13.1 Introduction

This section presents the environmental assessment for the effects of the project on traffic as per the project's terms of reference (Section E8). The information presented includes details on:

- Potential issues regarding changes to traffic.
- Projected increases in traffic.
- Mitigation measures incorporated in the project design for these impacts.

Results of this assessment are used to aid in assessing other potential impacts for major hazards (Section C2.6), air quality (Section C2.8), noise and vibration (Section C2.9), flora (Section C3.1) and socio-economics (Section C4.1). This assessment is limited to concession traffic. Traffic between the concession and the ports is discussed in the analysis of alternatives (A3) and major hazards (B2.6) sections.

Baseline information concerning traffic has been provided in Section B2.13.

A glossary of terms and acronyms used is presented at the end of this volume.

C2.13.2 Study Areas

The assessment study areas for traffic are the same as the terrestrial study areas, which include a Regional Study Area (RSA) and a Local Study Area (LSA).

The assessment RSA is a rectangle approximately 16 by 30 kilometers in size (Figure C1.6-1). The RSA contains the assessment LSA, numerous urban settlements (including Fungurume, Tenke, Mulumbu and Lukotola) and various infrastructure developments (including an airstrip, power lines, roads and railway tracks).

The LSA contains the main access roads for the project, as well as the haul roads and roadways to ancillary facilities such as the airstrip, limestone quarry and construction camp/permanent village.

C2.13.3 Impact Assessment

C2.13.3.1 Issue Scoping

The anticipated key issues relating to road and rail traffic are:

- Increased disturbance to populations along roadsides and rail routes due to dust, noise and vibrations with stronger impacts adjacent to unpaved roads.
- Increased incidents or accidents, both to people and to their animals, arising from potential increased flows and speeds of traffic as a result of improvements and upgrades to roads and rail, and increased project-related traffic.
- Increased potential risk of contamination of land and water resources due to spills resulting from traffic accidents involving the transport of industrial or hazardous goods.
- Increased traffic congestion due to increased traffic volumes, particularly in the towns of Tenke and Fungurume.
- Increased project-induced migration resulting from improved road access and increased traffic flows.

Issues relating to traffic noted during the public consultation process (Section A6.1) include concerns about further deterioration of roads in already poor condition as a result of increased traffic (particularly from heavy vehicles), and concerns regarding potential accidents as result of increased traffic along roads near and through the concession.

C2.13.4 Changes in Traffic

C2.13.4.1 Assessment Methods

Plans for mine, road and facility development were reviewed in the context of known baseline conditions for traffic. Professional experience in relation to the changes in traffic generally caused by mining, plant sites, waste rock facilities, quarries and associated developments was used to develop an understanding of the potential effect of the project. The approximate number of vehicles required for project construction and operation is known and was used to calculate changes in traffic volumes.

The effects of traffic on major hazards (Section C2.6), air quality (Section C2.8), noise and vibration (Section C2.9), flora (Section C3.1) and socio-economics (Section C4.1) are presented in their respective sections.

C2.13.5.1 Results

Traffic impacts will occur throughout the construction and operation phases of the project. Construction phase effects relating to traffic are often more pronounced, as there is movement of equipment, construction materials and personnel to and from the site. Moreover, construction workforces are generally larger than those required during the operation phase, and aspects of the construction process itself – including the construction or improvement of roads and facilities adjacent to roadways – can impede the flows of (increased) traffic. Given, however, project plans to house and transport construction workers, as well as the very low numbers of private vehicles currently using the roadways, traffic impacts related to the construction workforce will be less pronounced.

C2.13.6.1 Traffic Volumes

Changes in traffic volumes resulting from the project are based on estimates of the number of personal cars, mine vehicles, supply trucks and buses (transporting workers) that are required on a daily basis for the construction and operation of the project. The number of daily vehicle trips required during the construction and operation phases of the project is summarized in Table C2.13-1.

During the construction phase, traffic access will be along the road from Likasi to Fungurume, using the Kambove to Kakanda mine road and cutoff to the TFM camp through the concession. This road will be re-routed along the final 1.5 kilometers to bypass south of the TFM camp and intersect National Road Number 1. Access will continue on the Fungurume bypass road and intersect with the Mulumbu access road to reach the Kwatebala plant site.

This northern access route will convey 100 percent of traffic to and from the site (including the movement of supplies, reagents, product and personnel) during construction and initial years of production. The southern access route along National Road Number 1 to the Kafwaya cutoff road may serve as the primary route for the transport of product and reagents for the remainder of the life of the project (Years 5 to 20), and will be available for light vehicle traffic. However, this route is not planned as the main access for construction, or for the transport of product and reagent during the initial years of operation. Once constructed, an estimated 20 percent of light vehicle traffic is expected to utilize the southern access route. The transport of personnel will continue along the northern (Mulumbu) access road throughout the life of the project. The future use of a southern route (including the Kafwaya cutoff road and a section of National Road Number 1) are discussed under mitigation measures.

Table C2.13-1 Traffic Volumes – Round Trips per Day

Project Phase	Vehicle Types	Southern Access Route (Kafwaya Cutoff Road and National Road Number 1)			Northern Access Route (Mulumbu Access Road)		
		Current[(a)]	Projected[(b)]	% Increase	Current[(a)]	Projected[(b)]	% Increase
construction (Years -2 and -1)[(c)]	cars	10	10	0	6	21	250
	buses	6	6	0	0	57[(d)]	5,700
	light trucks/vans	22	22	0	14	33	136
	trucks/heavy equipment	4	4	0	18	32	78
	Total	**42**	**42**	**0**	**38**	**143**	**276**
operations (Years 1 to 4)[(e)]	cars	10	10	0	6	21	250
	buses	6	6	0	0	18[(f)]	1,800
	light trucks/vans	22	22	0	14	33	136
	trucks/heavy equipment	4	4	0	18	134	644
	Total	**42**	**42**	**0**	**38**	**206**	**442**
operations (Years 5 to 20)[(g)]	cars	10	14	40	6	17	200
	buses	6	6	0	0	18[(h)]	1,800
	light trucks/vans	22	29	32	14	26	107
	trucks/heavy equipment	4	103	2,475	18	35	94
	Total	**42**	**152**	**262**	**38**	**96**	**153**

(a) Estimates of current traffic volumes are based on baseline traffic surveys (see Section B2.13), conducted during daytime hours at midweek. These estimates are therefore likely to represent minimal traffic volumes.

(b) Projected traffic volumes include current traffic plus estimated project-related traffic. Potential increases in non-project traffic (including potential increases resulting from regional or national economic growth) have not been estimated. Project-related traffic estimates are based on projections for vehicle requirements during construction and production as detailed in the project description.

(c) Assumes the northern access route will be the primary route for the movement of materials, supplies and personnel during construction.

(d) Number of buses based on a peak estimated construction workforce of 2,640, and project description estimates of a workforce bus fleet consisting of 85-seat and 20-seat buses. Assumes a 75-25 ratio of 85-seat and 20-seat buses.

(e) Assumes the northern access route will be the primary route for the movement of materials, product, reagents and personnel for initial years of operation.

(f) Based on an estimated operations workforce of 840, and a workforce bus fleet consisting of 85-seat and 20-seat buses. Assumes a 75-25 ratio of 85-seat and 20-seat buses.

(g) Assumes that the construction of the southern access route (including the Kafwaya cutoff road and the Fungurume bypass road) will occur by year five of operations. Also assumes that approximately 20 percent of light vehicle traffic (cars and light trucks/vans) along the northern access route will shift to the southern route, and that the southern route will serve as the main reagent and product transport route. Personnel access will continue along the northern access route (Mulumbu access road).

(h) Based on an estimated operations workforce of 840, and a workforce bus fleet consisting of 85-seat and 20-seat buses. Assumes a 75-25 ratio of 85-seat and 20-seat buses.

Given the extremely low numbers of motorized vehicles currently on the roadways, changes in traffic represent, proportionately, a considerable increase in

traffic volumes, particularly along the access roads. Along the northern access route, the greatest impacts of the project in relation to traffic volumes will occur during construction and the initial years of operation (years one to four). The number of cars along the northern access route will increase by 250 percent during construction and initial operations, while light truck traffic will increase by 136 percent. Heavy vehicle traffic will increase more modestly during construction (by 78 percent), but will increase six-fold during the initial years of operation, rising from an average of 18 trips per day up to 134 round trips per day. Approximately 57 bus trips will be made daily along the route, where there is currently no bus access. Overall, motorized vehicle traffic along the northern access route will increase by approximately 276 percent during construction, and by approximately 442 percent during the initial years of operation.

Increases in traffic volumes along the northern access route will have the greatest potential impact in relation to bicycle and pedestrian traffic. Foot and bicycle traffic comprise the majority of traffic volume along the access route (see Section B2.13). The considerable increases in vehicle traffic present proportionate potential increases for person-vehicle interactions, and potential accidents.

Along the southern access route, the greatest impacts of the project in relation to traffic volumes will occur during later years of operation (years five to fifteen). As the southern route is opened as the main transportation corridor for the movement of reagents and product, overall traffic volumes will increase by approximately 262 percent (and will subsequently decrease along the northern access route). Of this, the majority of the increase will occur in heavy vehicles, as trucks previously utilizing the northern route will be diverted to the southern access route. This will represent a considerable increase in traffic, increasing from approximately four trucks per day to 103 trucks per day. Light vehicle traffic (including cars and light trucks) will increase more modestly, by approximately 40 percent and 32 percent respectively.

Again, increases in traffic volumes along the southern access route will have the greatest potential impact in relation to bicycle and pedestrian traffic. The considerable increases in vehicle traffic present proportionate potential increases for person-vehicle interactions, and potential accidents.

Some access will be required along the existing roads from the Mofia Limestone Quarry to the Mulumbu access road to haul aggregate to the plant site, and to transport aggregate to the construction camp. Little (if any) project-related traffic is expected along the roadway between Lukotola and the quarry, and therefore no project-derived traffic issues are anticipated.

C2.13.5 Mitigation

The Mulumbu access road to the north of the mine area will be the primary route for importing and exporting materials during construction and the project's initial years. It will also be used to transport personnel over the life of the project. At present, it is a minimally constructed road surviving from the Société Minière de Tenke Fungurume (SMTF) development undertaken in the 1970s. The Mulumbu access road will be graded and widened to safely accommodate pedestrian and bicycle traffic, separating these from motorized vehicle traffic and thereby reducing person-vehicle encounters and potential accidents (see Section A4.2).

The Kafwaya cutoff road may serve as the main reagent and product transport route between the National Road Number 1 and the processing plant in later years. A section of the National Road Number 1 between the Kafwaya cutoff road and Fungurume will be incorporated as part of this access route. In order to minimize person-vehicle interactions and potential accidents, these roads will be a maximum of about 28 meters in width, providing for two-way traffic, pedestrian and bicycle access, and drainage.

A bypass route (Fungurume bypass road) will also be constructed to the west of Fungurume, eliminating the need for large vehicles serving the plant site to pass through the village. While reducing potential accidents along this section of the roadway, the construction of the Fungurume bypass road will also eliminate wear on the road passing through Fungurume by diverting heavy vehicle traffic. In all instances, the roads that bisect Fungurume will be avoided wherever possible, and will only be used if no other access route is available (such as during a bridge washout, or if road construction blocks a passage route).

Other roads in the mine area will be constructed of compacted laterite, and will allow access to areas not served by the Mulumbu access road to the north and the National Road Number 1 to the south.

In addition to measures that are to be built into the project design (including the construction of new roadways and upgrading existing roads), the implementation of a number of safety measure (including speed limits, drivers' education, public education, vehicle scheduling, and vehicle maintenance) will reduce the potential for accidents along roadways within the concession (see Section A4.2).

C2.13.6 Conclusions

The project will result in traffic increases along the Mulumbu access road (including the Fungurume bypass road), and along the southern access route comprised of the Kafwaya cutoff road and a section of the National Road

Number 1. The greatest impacts will occur along the northern route during construction and initial years of operation (Years 1 through 4), and during later years of operation along the southern access route. Overall vehicle traffic along the northern access route will increase by approximately 276 percent during construction, and by approximately 442 percent during initial years of operation. Along the southern route, overall vehicle traffic will increase by approximately 262 percent during years five to fifteen. Such changes in traffic volume are likely to result in proportional increases in person-vehicle interactions and potential accidents. The implementation of safety measure such as speed limits, drivers' education, public education, and scheduling and maintenance of vehicles will reduce these impacts.

Increases in heavy vehicle traffic along both access routes are likely to be the greatest source of traffic impacts. Both the high volumes of heavy trucks and buses along the routes throughout the life of the project, and the potential wear on roadways caused by increases in heavy vehicle traffic will require specific mitigation measures.

The project is expected to bring about overall improvements in transportation infrastructure. Increases in traffic volumes along the northern and southern access routes will be mitigated by the construction, upgrading and maintenance of the Mulumbu access road, Kafwaya cutoff road and the Fungurume bypass road. The diversion of heavy vehicle traffic around Fungurume and along the Kafwaya cutoff road will particularly ease bicycle and pedestrian travel, as well as the movement of light vehicles, through Fungurume and along the National Road Number 1. Given the high volume of bicycle and pedestrian traffic along the access routes, measures that will reduce wear on roads that are currently in poor repair and condition will be necessary to mitigate potential traffic impacts.

C3.1 FLORA

C3.1.1 Introduction

This section presents the environmental assessment for the potential effects of the Tenke Fungurume Mining (TFM) project on flora. The information presented meets the requirements of the TFM project's terms of reference (Appendix E8). Site-specific data were collected to address the following elements as they relate to flora within the project area:

- Potential issues and project activities that may affect plant communities, species diversity and plant species, including copper-cobalt flora.
- Mitigation incorporated in the project design for these potential impacts.
- Methods used for the analysis of the potential effects on flora.
- Impact assessment approach and results for key flora issues.
- Sustainability assessment approach and results for key flora issues.
- Identified measures relating to flora to promote long-term economic and social sustainability in the project area.

This section is organized as follows:

- Section C3.1.2 describes the study areas.
- Section C3.1.3 discusses the impact assessment approach and results.
- Section C3.1.4 provides the cumulative effects assessment.
- Section C3.1.5 discusses the conclusions of the assessment.

Baseline information concerning flora is provided in Section B3.1, and a flora action plan in Section D3.1.11. The flora action plan is supported by a section that describes strategies for the conservation of copper-cobalt flora (Appendix D3.1-I), which is further supported by a biological diversity action plan (Appendix D3.1-II). The strategy and action plan appendices present details of the conservation approaches, specific methodologies, needed resources, timetable and success/performance monitoring criteria for the copper-cobalt flora conservation program.

A glossary of terms and acronyms used in this section is provided at the back of this volume.

C3.1.2 Study Areas

The study areas for the flora impact assessment (Section C3.1) are the same as those for the flora baseline (Section B3.1).

The terrestrial (land-based) Regional Study Area (RSA) for soil, flora, fauna and biodiversity components is a rectangle extending about 16 kilometers from north to south and 30 kilometers from east to west (Figure C1.6-1). The RSA contains nearly the entire Dipeta catchment and the southern portion of the Mofia catchment. The RSA includes areas that are likely to be affected by any future expansion of the project.

The terrestrial Local Study Area (LSA) is located between the towns of Tenke and Fungurume. The LSA is made up of the ore body complex (Kwatebala Hill, Goma hills and the Fwaulu hills). It contains the proposed mine and processing plant, the tailings storage facility and waste rock facilities, the main access road, powerline route, and all other infrastructure relating to the project. The LSA also includes the site of the proposed limestone quarry located about 10 kilometers north of Fungurume (Figure C1.6-1). The LSA for all of the project components was extended by a buffer of 500 meters to account for potential indirect effects. The LSA includes the area that is likely to experience the highest direct and indirect impact on flora due to development of the TFM project.

C3.1.3 Impact Assessment

C3.1.3.1 Issue Scoping

The anticipated key issues relating to flora are:

- Impacts on rare and important plant communities or communities supporting high species richness.
- Loss of vulnerable, threatened or locally endemic (native) plant species or potential critical habitat, as defined by the World Conservation Union (IUCN), and incorporated by reference into the terms of Performance Standard 6 (PS-6) (IFC 2006C).
- Loss of medicinal plants.
- Loss of forest species.
- Reduction of plant species diversity.
- Impacts on plant health.

- Indirect losses to flora as a result of changes in air quality and/or surface water and groundwater flows.
- Introduction of invasive exotic (non-native) and native nuisance species into native plant communities adhering to IFC Performance Standard 6 (PS-6) (IFC 2006c).

Issues relating to impacts on flora noted during the public consultation process (Section A6) include:

- Concern that the construction of mine infrastructure and facilities will result in the loss of vegetation including trees.
- Concern that increased population in the area resulting from mine construction and operations employment will further reduce vegetation including trees.
- Concerns regarding the potential impacts that mine facilities and infrastructure may have on the availability of medicinal plants, particularly on Kwatebala Hill.

Sustainability issues relating to flora include:

- The effect of induced population growth in the RSA on plant communities.
- The loss of miombo woodland and gallery forest (forest along a water course) cleared to accommodate increasing demands for agricultural land.

C3.1.3.2 Key Questions and Indicators

Project-related activities that are expected to impact flora include construction and operation of the mine and processing plant, the construction of the tailings storage facility and waste rock facilities, access roads and powerlines, the limestone quarry and other project infrastructure. The key questions relating to the impact of these activities on flora assess negative and positive changes at the community and species level (Table C3.1-1).

Table C3.1-1 Key Questions for Flora

Impact Assessment	
Key question FL-1:	To what extent will the project result in loss or alteration of plant communities and reduced species diversity?
Key question FL-2:	Will the project increase the risk of loss of plant species (species extirpation or extinction)?
Sustainability Assessment	
Key question FL-3:	How can the project reduce the rate of miombo woodland and gallery forest degradation?

Indicators relating to the effects of the project on flora are listed in Table C3.1-2. Several of these indicators are measured in this environmental and social impact assessment (ESIA) through an assessment of the amount of land affected by the project in a variety of habitats. The number of plant species with the potential for extirpation (destruction) or extinction (no longer in existence) is measured as a quantitative indicator. Loss of plant species diversity, reduced plant vigor and productivity are reviewed as qualitative indicators as they relate to:

- Airborne dust.
- Dispersion of sulfur dioxide (SO_2) and nitrogen oxides (NO_x).
- Changes in surface water hydrology, through changes in evapotranspiration, storm water runoff, etc.
- Changes in groundwater due to dewatering of the mine pit.
- Influences from non-native (exotic) and native nuisance plant species.

Plans for the protection and restoration of habitats will also be reviewed as qualitative indicators.

C3.1.3.3 Assessment Criteria

The impact criteria used to assess impacts resulting from the TFM project's mining activities are presented in Table C3.1-3.

C3.1.3.4 Key Question FL-1

Key question FL-1 is: What effect will the project have on loss or alteration of plant communities and reduced species diversity?

The plant communities of greatest concern contain three species that are potentially classifiable as 'critically endangered' if evaluated by the IUCN. These three species include *Cheilanthes* sp. nov., *Chlorophytum* sp. nov. and *Faroa malaissei*. Since there are limited known records for these three species outside of the project footprint, their present area of distribution are considered potentially classifiable as critical habitat under the same IUCN criteria. The mitigation actions proposed by the project provide a means for protecting the potential critical habitats and the species they host. Without the project, artisanal mining will continue in an uncontrolled manner likely removing the habitat and causing extirpation of the species. As required by guidelines in IFC PS-6 (IFC 2006c), there will be no loss of critical habitat within the LSA. Mitigation plans will protect all critical habitats within the project footprint resulting in no extirpation or extinction of species.

Table C3.1-2 Potential Flora Indicators and Key Questions

GRI Indicator [a]		ESIA Indicators	Context	Key Questions	
EN6	location and size of land owned, leased, or managed in biodiversity-rich habitats	total amount of land affected by the project for each important plant community type	using mitigation and the creation of sustainability programs, effects on native miombo woodland, gallery forest, and copper-cobalt flora will be minimized	FL-1	To what extent will the project result in loss or alteration of plant communities and reduced species diversity?
				FL-3	How can the project reduce the rate of miombo woodland and gallery forest degradation?
EN23	total amount of land owned, leased, or managed for production activities or extractive use				
EN26	changes to natural habitats resulting from activities and operations and percentage of habitat restored identify type of habitat affected and its status	total amount of land reclaimed in each important plant community type			
EN27	objectives, programs, and targets for protecting and restoring native ecosystems and species in degraded areas	total amount of land undisturbed by the project or restored			
EN28	number of IUCN Red List species with habitats in areas affected by operations	species richness and number of IUCN Red List[b] species in land disturbed by the project	the copper-cobalt plant communities contain rare and endangered plant species	FL-2	Will the project increase the risk of loss of plant species (species extirpation or extinction)?
EN32	water sources and related ecosystems/habitats significantly affected by discharges of water and runoff	total amount of wetland and gallery forest affected by changes in discharge	wetland and gallery forest are dependent upon streams as a water source	FL-1	To what extent will the project result in loss or alteration of plant communities and reduced species diversity?

[a] Global Reporting Initiative (GRI 2005b).

[b] International Union for the Conservation of Nature and Natural Resources (IUCN 2001).

Table C3.1-3 Impact Description Criteria for Flora

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 (less than 1%) on the measured endpoint **low:** less than 10% change on the measured endpoint **moderate:** 10 to 20% change on the measured endpoint **high:** more than 20% change on the measured endpoint	**local:** effect restricted to the LSA **regional:** effect extends beyond the LSA into the RSA **beyond regional:** effect extends beyond the RSA	**short-term:** less than 3 years **medium-term:** 3 to 20 years **long-term:** more than 20 years	**reversible** or **irreversible**	**low:** occurs once or rarely **medium:** occurs intermittently **high:** occurs continuously

[a] Direction: positive or negative effect for measurement endpoints.

[b] Magnitude: degree of change to analysis endpoint (the loss in plant community size). Based on a risk assessment approach, Suter et al. (1995) have identified that the 20 percent rule for the severity of effects from contamination is applicable to varying spatial scales of ecological effects (i.e., a 20 percent change in a measurement endpoint constitutes an ecological effect).

[c] Geographic Extent: area affected by the impact.

[d] Duration: length of time over which the environmental effect occurs. Considers a two-year construction period and a 20-year operation period.

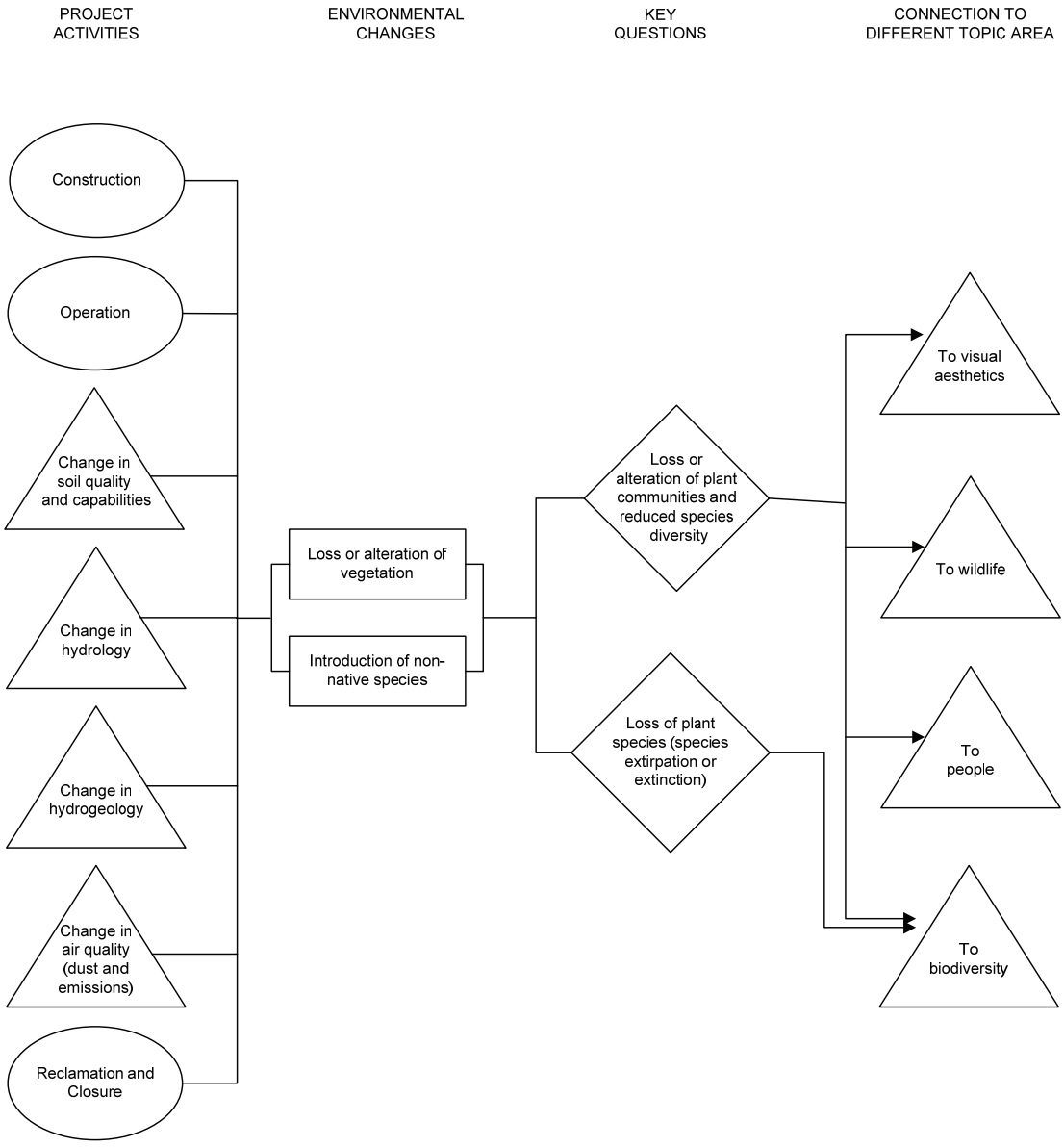
[e] Reversibility: effect on the resource (or resource capability) can or cannot be reversed.

[f] Frequency: how often the environmental effect occurs. Once or rarely indicates an impact one time during the project or of rare occurrence during the project (once a year or less). Intermittently refers to impacts that are seen more than once a year, but not continuously.

Linkage Evaluation

The construction and operation phases of the TFM project could result in the loss or alteration of plant communities or reduced species diversity through land clearing and changes in soil quality and capabilities, surface and groundwater quantity, air quality, land use and natural risks. All of these factors could affect visual aesthetics (visual appeal), wildlife, socio-economics and biodiversity as shown on the linkage diagram (Figure C3.1-1).

Figure C3.1-1 Flora Linkage Diagram



Assessment Methods

Impacts of the TFM project on plant communities were assessed through changes in the total area of vegetation types in relation to the local and regional conservation status of a given vegetation type. For example, *key plant communities* selected for this assessment were based on ecological importance and vulnerability, and diversity of species. These communities include:

- Copper-cobalt rock outcrop.
- Copper-cobalt steppe-savannah.
- Gallery forest.
- Miombo woodland.
- Wetlands.

Direct effects are related to site clearing. Indirect effects are related sulfur dioxide (SO_2) and nitrogen oxides (NO_X) emissions, changes in surface water levels, changes in groundwater and the influence of invasive exotic or native nuisance species.

Clearing Activities

The TFM project's footprint includes the mine area (e.g., mine, plant site, stockpile areas, tailings storage facility, waste rock facility, haul roads and borrow pits, from which road building material will be obtained), expansion of the road network, powerline, limestone quarry, and the construction camp/permanent village. The maximum extent of direct impact (vegetation loss due to site clearing) was assumed to be the entire area of the project footprint. The effect of revegetation and progressive revegetation, where feasible, during the operational phase of the project were not taken into account for a conservative estimate of impact.

Invasive Exotic (Non Native) and Native Nuisance Species

Construction and operation of the TFM project may lead to an increase in invasive exotic and native nuisance plant species by means of increased vehicle traffic and site clearings. There are no regulations in the Democratic Republic of the Congo (DRC) concerning such species. As a result, there is no legal obligation to manage invasive exotic and native nuisance plants in the mining concession. However, management of invasive exotic and native nuisance plants will comply with PS-6 (IFC 2006c). The impact assessment is based on professional judgment, taking into consideration the plants in the concession area that are known to be invasive, and the effect that the project could have on the proliferation of these plants.

Soil Quality and Capabilities

Information from soils (Section B2.4) includes discussions about current conditions of soil quality and capabilities. This was used to help assess the potential impacts of the TFM project on plant communities.

Surface Water Hydrology

The surface water hydrology assessment (Section C2.11) makes predictions on changes in stream flows and channel geomorphology. This was used to help assess the potential impacts on wetlands and gallery forests. Maintenance of baseflows in the Kasana, Sokalwela and Shimpidi rivers will be undertaken by TFM when pit dewatering is initiated in Year 8. Excess pit dewatering water could result in increased erosion and changes in channel morphology. As guidelines are not available for determining effects on flora based on hydrological changes, a qualitative approach was taken.

Groundwater

The hydrogeology assessment (Section C2.10) makes predictions on changes in groundwater. This was used to help assess the potential impacts on wetlands and gallery forests. As guidelines are not available for determining effects on flora based on hydrogeological changes, a qualitative approach was taken.

Air Quality

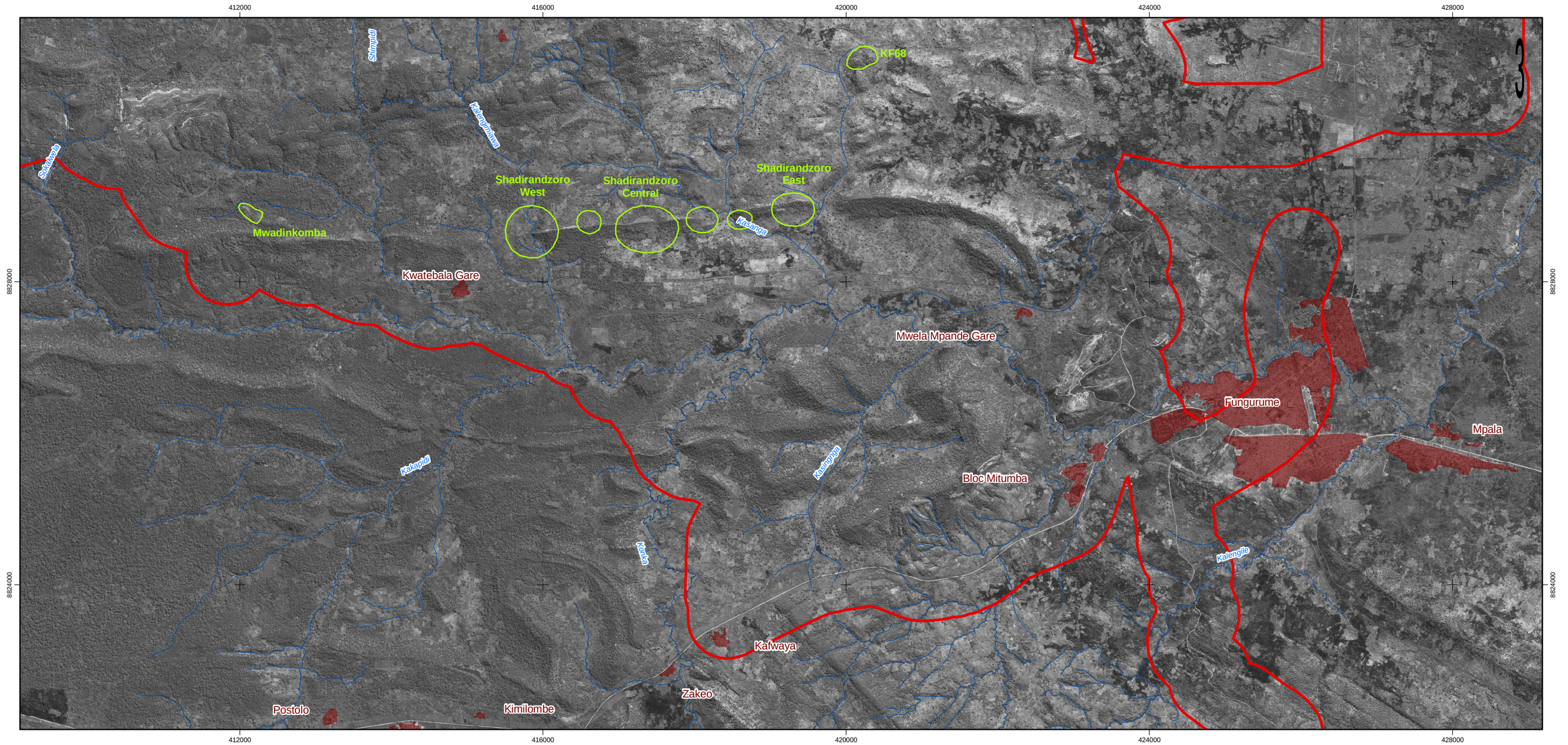
World Health Organization (WHO) guidelines provide the best available information on which to base impact assessment of sulfur dioxide and nitrogen oxides on plants (Table A2.7-4, Section A2.7.1.3). For this assessment, the more stringent value of 10 micrograms per cubic meter was used as the threshold above which the sulfur dioxide impact on plants is considered to be significant.

Mitigation

The following mitigation measures will be employed to minimize the magnitude, geographic extent and duration of direct impacts from the TFM project on the loss or alteration of plant communities. This section includes a summary of the mitigation detailed in the conservation strategies for copper-cobalt flora (Appendix D3.1-I) and the biological diversity action plan (Appendix D3.1-II), which are intended to protect all potential critical habitat in compliance with IFC PS-6 (IFC 2006c).

- Minimize the non-essential extent of the project footprint.
- Avoid unnecessary disturbances to copper-cobalt flora, gallery forest and miombo woodland.

- Commit to establishing two areas for ecosystem translocation/reconstruction, with precise locations yet to be determined, but likely to include mineralized areas identified in the Dipeta syncline (Figure C3.1-2) and translocation prior to site clearing of all potential critical habitat (areas containing Cheilanthes sp. nov. (found in area 1 on Figure C3.1-3), Chlorophytum sp. nov. (also in area 1) and Faroa malaissei (areas 3 and 4) that can be feasibly removed from Kwatebala Hill to the host areas. Note that area 1 is the first priority as it will be cleared in 2007. Areas 3 and 4 will not be cleared until 2008. Translocation of F. malaissei is of lower priority as this species is currently known for four hills. Other species of concern will also be transferred,, as opportunity presents, including, Basananthe kisimbae, Barleria lobelioides, Wahlenbergia verbascoides, Haumaniastrum robertii, and Pellaea pectiniformis var. nana).
- Establish a program to collect seeds and other propagation material from the project footprint for use in ecosystem reconstruction areas, seed banks, botanical gardens, and potentially for reclamation activities.
- Identify and establish plant micro-reserves (PMRs) that will preserve representative copper-cobalt flora in situ, within the concession. The PMRs will be located on areas that will not be disturbed for the life of the project (40+ years). It is anticipated that, in aggregate, these PMRs will contain most if not all of the plant species found on the hills to be mined. Several potential copper-cobalt PMRs have been identified at Fwaulu (Figure C3.1-4), parts of Fungurume Hill V and other hills in the TFM concession, though final mine plans for those resources have yet been developed.
- Protect and conserve flora species of concern (species that have not been formally listed but potentially meet IUCN-ranking criteria) in areas beyond the immediate project footprint but within areas of influence (e.g., copper-cobalt flora on land adjacent to the mine that will not be stripped).
- Set aside conservation areas, with an aggregate equivalent conservation value as Fungurume Hill V, with sites to be determined once further botanical and geological investigations within the concession area are completed through implementation of the BDAP. Decisions on the type and duration of conservation use to which copper-cobalt flora hills such as Fungurume Hill V would be dedicated will be made with input from the BDAP scientific team.
- Improve scientific knowledge of the occurrence and range of copper-cobalt flora by continuing the flora surveys on the hills within the LSA and extending them to copper-cobalt hills in the RSA and concession area.



LÉGENDE / LEGEND

- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- POTENTIAL ECOSYSTEM RECONSTRUCTION AREAS
- ZONE D'ÉTUDE LOCALE - TERRESTRE / LOCAL STUDY AREA - TERRESTRIAL

1.5 0 1.5

ÉCHELLE / SCALE 1:50000 1:50010 KILOMÈTRES / KILOMETERS

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

AIRES POTENTIELLES DE RESTAURATION D'ÉCOSYSTÈMES / POTENTIAL ECOSYSTEM RECONSTRUCTION AREA

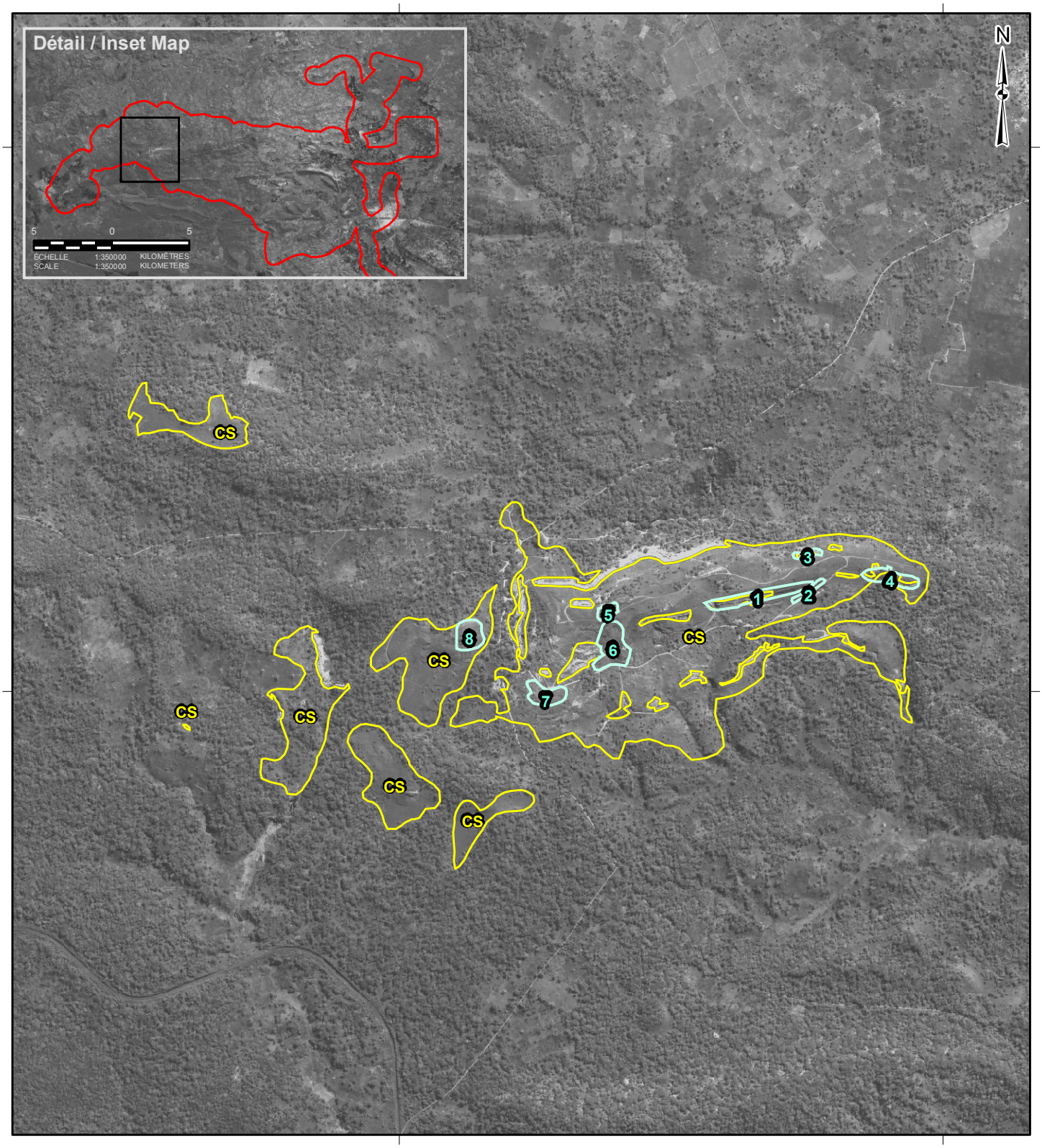
RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	CW	02 Feb. 2007		
GIS / SIG	AC	29 Mar. 2007		
VÉRIFIÉ / CHECK	MR	29 Mar. 2007		
APPROUVÉ / REVIEW	MR	29 Mar. 2007		

FIGURE: C3.1-2



LÉGENDE / LEGEND

FLORE HAUTEMENT SENSIBLE / HIGHLY SENSITIVE FLORA

1 = ESPÈCES PRIORITAIRES: CHEILANTHES SP.NOV. SOPUBIA NEPTUNEI HAUMANIASTRUM ROBERTII / PRIORITY SPECIES : CHEILANTHES SP. NOV. SOPUBIA NEPTUNEI, HAUMANIASTRUM ROBERTII

2 = FLORE UNIQUE : XEROPHYTA STEPPE / UNIQUE FLORA: XEROPHYTA STEPPE

3 = ESPÈCES PRIORITAIRES : FAROA MALAISSEI / PRIORITY SPECIES: FAROA MALAISSEI

4 = ESPÈCES PRIORITAIRES : FAROA MALAISSEI / PRIORITY SPECIES: FAROA MALAISSEI

5 = FLORE UNIQUE : STEPPE / SAVANE / UNIQUE FLORA: STEPPE SAVANNA

6 = FLORE UNIQUE : STEPPE / SAVANE (HUMIDE) / UNIQUE FLORA: STEPPE SAVANNA (HUMID)

7 = FLORE UNIQUE : STEPPE / SAVANE / UNIQUE FLORA: STEPPE SAVANNA

8 = ESPÈCES PRIORITAIRES : BASANANTHE KISIMAE / PRIORITY SPECIES: BASANANTHE KISIMBAE

FLORE SPÉCIFIQUE AU MINERAI DE CUIVRE-COBALT NON ENCORE ÉTUDIÉE / COPPER-COBALT FLORA NOT YET STUDIED

CS = STEPPE-SAVANE SUR SUBSTRAT CUPRO-COBALTIFÈRE / COPPER-COBALT STEPPE-SAVANNA

RÉFÉRENCE / REFERENCE

Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

500 0 500
ÉCHELLE 1:20000 MÈTRES
SCALE 1:20000 METERS

PROJET/ PROJECT: PROJET MINIER TENKE FUNGURUME / TENKE FUNGURUME PROJECT / TENKE FUNGURUME MINING SARL

TITRE/ TITLE: **ZONES PRIORITAIRES À KWATEBALA / PRIORITY FLORA AREAS AT KWATEBALA**

Golder Associates Calgary, Alberta

PROJECT No. 05-1334-035			SCALE AS SHOWN	REV. 0
DESIGN	DN	30 Jun. 2006		
GIS	AC	07 Mar. 2007		
CHECK	MR	31 Oct. 2006		
REVIEW	MR	31 Oct. 2006		

FIGURE: C3.1-3

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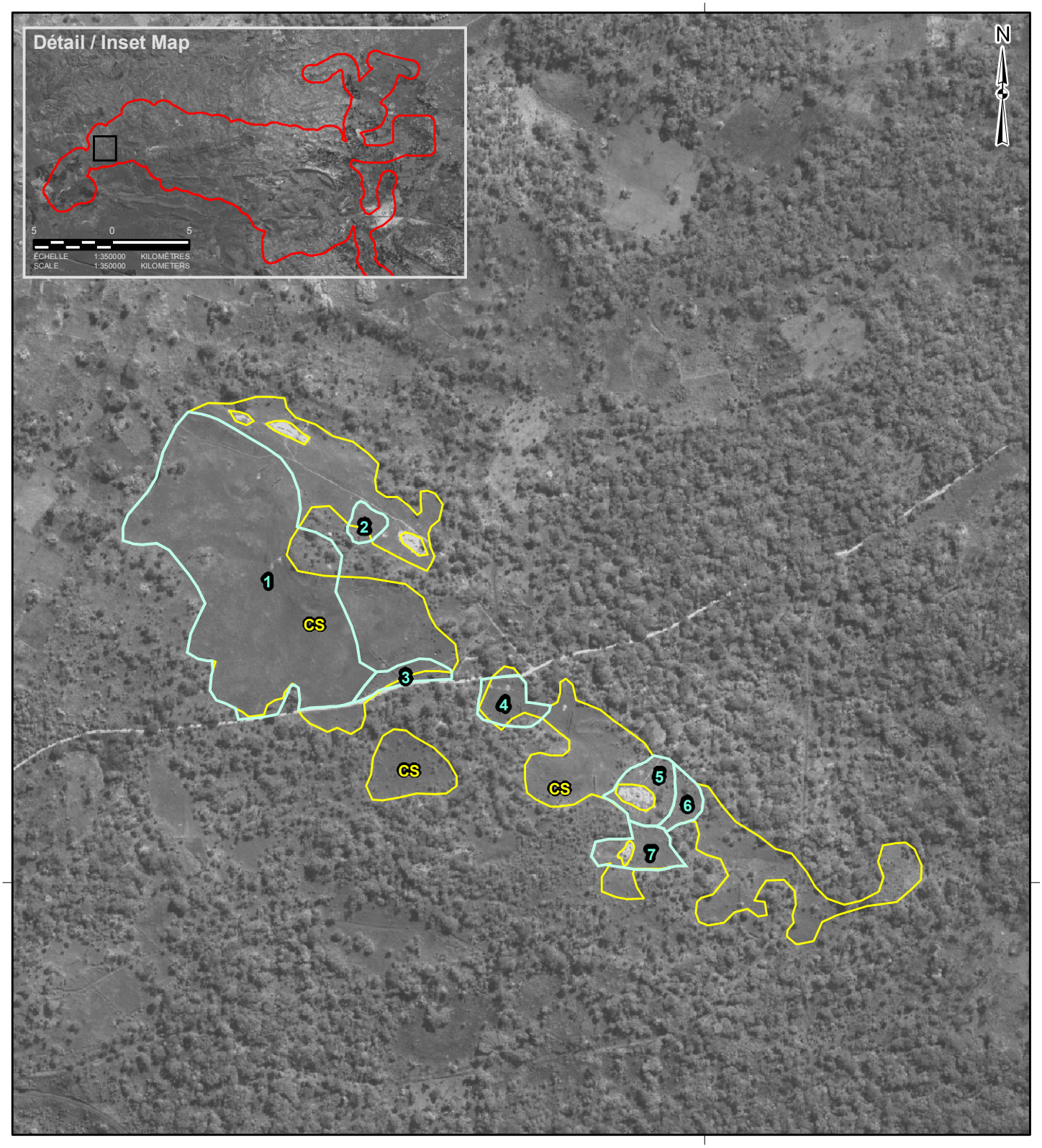


LÉGENDE / LEGEND

FLORE HAUTEMENT SENSIBLE / HIGHLY SENSITIVE FLORA

1 = RICHESSE DES ESPÈCES : TROISIÈME RANG POUR LE NOMBRE D'ESPÈCES À CARACTÈRE UNIQUE : STEPPE / SAVANE HUMIFÈRE / SPECIES RICHNESS: 3RD RANK IN SPECIES NUMBER ORIGINALITY : HUMIFEROUS STEPPE SAVANNA

2 = FLORE UNIQUE : COMPOSITION FLORISTIQUE SPÉCIFIQUE / UNIQUE FLORA: SPECIFIC FLORISTIC COMPOSITION

3 = ESPÈCES PRIORITAIRES : CYANOTIS SP. (POTENTIELLEMENT NOUVELLE POUR LA SCIENCE) / PRIORITY SPECIES: CYANOTIS SP. (POTENTIALLY NEW TO SCIENCE)

4 = FLORE UNIQUE : STEPPE / SAVANE AVEC ORCHIDÉES / UNIQUE FLORA: STEPPE SAVANNA WITH ORCHIDS

5 = ESPÈCES PRIORITAIRES : BASANANTHE KISIMBAE / PRIORITY SPECIES: BASANANTHE KISIMBAE

6 = ESPÈCES PRIORITAIRES : BASANANTHE KISIMBAE / PRIORITY SPECIES: BASANANTHE KISIMBAE

7 = FLORE UNIQUE: STEPPE / SAVANE SUR DALLE ROCHEUSE / UNIQUE FLORA: STEPPE SAVANNA ON ROCKY FLAG

FLORE SPÉCIFIQUE AU MINERAI DE CUIVRE-COBALT NON ENCORE ÉTUDIÉE / COPPER-COBALT FLORA NOT YET STUDIED

CS = STEPPE-SAVANE SUR SUBSTRAT CUPRO-COBALTIFÈRE / COPPER-COBALT STEPPE-SAVANNA

RÉFÉRENCE / REFERENCE

Projection: Mercator transverse. Système géodésique: WGS 84 Système de coordonnées: UTM Zone 35S
Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

250 0 250
ÉCHELLE 1:7500 MÈTRES
SCALE 1:7500 METERS

PROJET/ PROJECT: PROJET MINIER TENKE FUNGURUME / TENKE FUNGURUME PROJECT / TENKE FUNGURUME MINING SARL

TITRE/ TITLE: **ZONE PRIORITAIRE À FWAULU / PRIORITY FLORA AREAS AT FWAULU**

Golder Associates Calgary, Alberta

PROJECT No. 05-1334-035			SCALE AS SHOWN REV. 0
DESIGN	DN	30 Jun. 2006	
GIS	AC	12 Mar. 2007	
CHECK	MR	31 Oct. 2006	
REVIEW	MR	31 Oct. 2006	

FIGURE: C3.1-4

Project: I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\mxd\Tenke_ESIA\Volume C\FigureC3.1-4_Fwaulu_SensitiveAreas.mxd - Plot: I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\pdf\Tenke_ESIA\Volume C\FigureC3.1-4_Fwaulu_SensitiveAreas.pdf

- Protect the population of *Cheilanthes* sp. nov. found on Pumpi Hill XI from disturbance until it can be demonstrated that the translocated Kwatebala population is successfully established in the new host area.
- Commit to undertaking trial reclamation activity on small portions disturbed areas, as per the biological garden (ecosystem reconstruction) approach, to build credibility for this approach.
- Continue to collect comprehensive data on copper-cobalt flora in the LSA, including focused programs to find *Cheilanthes* sp. nov., *Chlorophytum* sp. nov. and *Faroa malaissei*.
- Reclaim copper-cobalt flora, gallery forest and degraded miombo forest following recommendations in the flora action plan (Section D3.1.12) during operations and after closure of the project.
- Implement dust control measures, particularly within the mine site and along roads, during all phases of the project.
- Augment baseflows in the Kasana, Sokalwela and Shimpidi rivers with excess pit dewatering water as available. Due to the uncertainty of this mitigation in preserving gallery forests in areas where groundwater levels may be lowered by project related activities, an equivalent area of gallery forest habitats will be restored along degraded sections of streams within the concession area.
- Should erosion of river banks be shown to be an issue during flow augmentation, release water or implement erosion-control measures such that erosion levels are acceptable, or pipe water to the Dipeta River for release.
- Provide public education on the importance of biodiversity and copper-cobalt flora.
- Support the University of Lubumbashi so that long-term research can be undertaken and local capacity established, in particular in the establishment of a seed-bank and in sponsorship of graduate student research.

Results

Direct Effects

Clearing Activities

Direct losses of vegetation as a result of the construction and operation of the mine, processing plant site, tailings storage facility, infrastructure and related project components will amount to 2,370 hectares (16 percent of the LSA) (Table C3.1-4). The vegetation type that will have the greatest proportional loss in the LSA is the copper-cobalt rock outcrop. Without mitigation there would be a loss of nine hectares (82 percent of the vegetation in the LSA). However with proposed mitigation, an equivalent of four hectares of rock outcrop will be

translocated to an ecosystem reconstruction area reducing the loss to five hectares (47 percent of the vegetation type in the LSA). The next highest disturbance is to the copper-cobalt steppe-savannah (185 hectares or 37 percent of the vegetation type in the LSA). These two plant community types occur on the copper hills where mining operations for the project are focused. These two plant communities, however, are already highly disturbed in areas from artisanal mining activities. The direct effects of clearing activities from this project are not to pristine vegetation communities.

Table C3.1-4 Area of Vegetation Types and Change in Area as a Result of Site Clearing and Reclamation within the Local Study Area

Vegetation Type	Areas by Project Phase			Vegetation Change			
	Baseline	Construction /Operation	Reclamation /Closure	Baseline to Construction/ Operation		Baseline to Reclamation/ Closure	
	Hectares	Remaining Hectares	Remaining Hectares	Hectares	Percent	Hectares	Percent
Existing vegetation types							
agricultural mosaic	9,469	8,175	8,484	-1,294	-14	-985	-10
copper-cobalt rock outcrop[(a)]	11	6	6	-5	-47	-5	-47
copper-cobalt steppe-savannah	503	317	334	-185	-37	-168	-34
gallery forest	37	36	37	-1	-3	0	0
miombo woodland	3,327	2,808	2,808	-519	-16	-519	-16
miombo woodland degraded	1,168	805	1,446	-364	-31	277	24
wetland	34	33	33	-1	-4	-1	-4
subtotal	*14,550*	*12,179*	*13,147*	*-2,370*	*-16*	*-1,402*	*-10*
Non-vegetated and erosion control vegetation types							
disturbance	268	2,638	844 [(b)]	2,370	884	576	215
erosion resistant shrubland and/or grassland	0	0	826	0	0	826	n/a
subtotal	*268*	*2,638*	*1,670*	*2,370*	*884*	*1,402*	*523*
Total	**14,818**	**14,817**	**14,817**	**0**	**n/a**	**0**	**n/a**

[(a)] Numbers include 4 ha equivalent of copper rock outcrop to be translocated to an ecosystem reconstruction area.

[(b)] Includes portions of the mine pit not to be revegetated and infrastructure left in place following project closure (e.g., new roads and village).

Notes: Due to rounding conventions, numbers may not equal totals.

All values in text reflect intact habitats as indicated by vegetation type.

n/a = not applicable.

A total of 519 hectares of miombo woodland and 364 hectares of degraded miombo woodland will be lost as a result of the project (16 percent and 31 percent of the vegetation types in the LSA, respectively). A total of 1,294 hectares of the agricultural mosaic (a mosaic of cropland and grassland; Section B3.1) will be lost (14 percent of the vegetation type in the LSA). The powerline will be located predominantly on the agricultural mosaic vegetation type. One hectare of gallery forest will also be lost from direct impacts (three percent of the vegetation type) and one wetland one hectare in size will be lost. This wetland is isolated and relatively degraded around its perimeter from agricultural use. Its major significance is as a source of water and location of dry-season agriculture for local residents, and effects on these values are addressed in the socio-economic section (C4-1). The goal is to reclaim wooded areas such as gallery forests and miombo woodlands to at least a state similar to pre-project conditions, where feasible, and therefore the area values in Table C3.1-4 reflect an increase in these vegetation types from the construction and operation periods.

Indirect Effects

Indirect effects on plant communities will result from changes in soil quality and capabilities, surface water hydrology, hydrogeology, air quality and increased disturbance caused by the migration of people into the study area in search of work. These effects may cause plant habitat loss in the affected areas, reductions in plant vigor and productivity or reductions in site-specific species diversity. These predicted effects (outlined below) are conservative. Where available, these predicted effects are based on guidelines, other published literature and professional judgment.

Soil Quality and Capabilities

The majority of the disturbance will occur in soil map units 2 and 3 (1,394 and 391 hectares, respectively) (Section C2.4). These soil types are associated with many plant communities, not just one plant community. The disturbances that will affect flora include soil removal, mixing of soil horizons and soil types, loss of organic matter, compaction and contamination.

Removal of the metalliferous (soils containing metal) soils at the mine sites will have the greatest consequences as the copper-cobalt flora is dependent upon the metal concentrations. The relationship between soil toxicity and these rare copper-cobalt plants is not well known. There is no empirical evidence available to show the range of soil toxicity that the copper-cobalt flora will tolerate and the extent to which the flora can reproduce in disturbed soil conditions. The loss of these soils may therefore result in the permanent loss of copper-cobalt flora from the mining sites. If mixed and used for rehabilitation outside of copper-cobalt areas, these soils containing metal could also greatly reduce land capability by

limiting plant growth and diversity. This would reduce the reclamation potential of the area.

Outside of the copper-cobalt areas, soils are mostly moderately to highly suitable for most crops grown in the area. Soil acidity and low levels of fertility are the main limitations to agricultural production. Soil erosion could also be a long-term limitation on slopes over 5 to 10 degrees.

Surface Water Hydrology

It is forecast that, without mitigation, the project will reduce baseflows in the Kasana, Sokolwela and Shimpidi rivers (Section C2.11). This could cause long-term damage to gallery forest along the three affected rivers. While agricultural practices in the study area have impacted gallery forest, there are still some gallery forest areas remaining along the three watercourses that could be impacted by flow reductions.

The surface water hydrology assessment predicted effects on flows for the first seven years of mining when no pit dewatering will take place, and the final eight year of mining when dewatering water, intercepted by boreholes, will be used to augment total season flows in local streams (Table C3.1-5).

Table C3.1-5 Potential Flow Changes on Total Flow by the Project

Node	River	Year 7 Flow Change[(a)(c)(e)]		Year 15 Flow Change. Mitigated Scenario[(c)(d)]	
		Wet Season (%)	Dry Season (%)	Wet Season (%)	Dry Season (%)
KAS1	Kasana	-20	-10	-78	-90
MOF1	Mofia	-1.3	-0.7	-5.0	-5.8
MOF2	Mofia	-0.9	-0.5	-3.6	+4.2
KAB1	Kabomboy	+3.6[(f)]	+12.3[(f)]	+3.6[(e)]	+12.3[(e)]
KAB1	Kabomboy	+1.5[(g)]	+4.9[(g)]	+1.5[(f)]	+4.9[(f)]
DIP1	Dipeta	-1.7	-1.9	-12	-16
DIP2	Dipeta	-0.8	-0.9	-5.4	-7.3
MOF3	Mofia	-0.5	-0.3	-2.1	-2.4
SOK1	Sokalwela	-9.0	-10	-80	-85
SHM1	Shimpidi	-9.0	-10	-44	-65
TSH1	Tshilongo	0[(c)]	0[(c)]	0[(f)]	0[(f)]

(a) Key question SWH-1, Section C2.11.

(b) Key question SWH-2, Section C2.11.

(c) A reduction in flow is noted by a minus (-) sign. An increase in flow is noted by a plus (+) sign. Zero percent change represents a negligible effect.

(d) Impacts do not include the effect of the proposed mining of the Goma and Fwaulu deposits.

(e) Represents high flow change scenario of 200 liters per person per day being released from the sewage treatment plant to the Kabomboy River.

(f) Represents low flow change scenario of 80 liters per person per day being released from the sewage treatment plant to the Kabomboy River.

(g) The future mining activities at Goma do not appear to be in the Tshilongo River catchment.

Residual wet season flows are predicted to change from +4 to -78 percent during the entire life-of-mine. Such changes are not expected to affect gallery forest as water availability is not restricted during the wet season. Residual dry season flows are predicted to change from +12 to -90 percent. This change will have a moderate effect on gallery forest, especially along the Kasana River after Year 8 of mining.

Effects to stream geomorphology are predicted to be negligible (Section C2.11) if the appropriate mitigation (erosion-control measures, controlled release of water, piping of water to the Dipeta River) is used for the release of excess pit dewatering water.

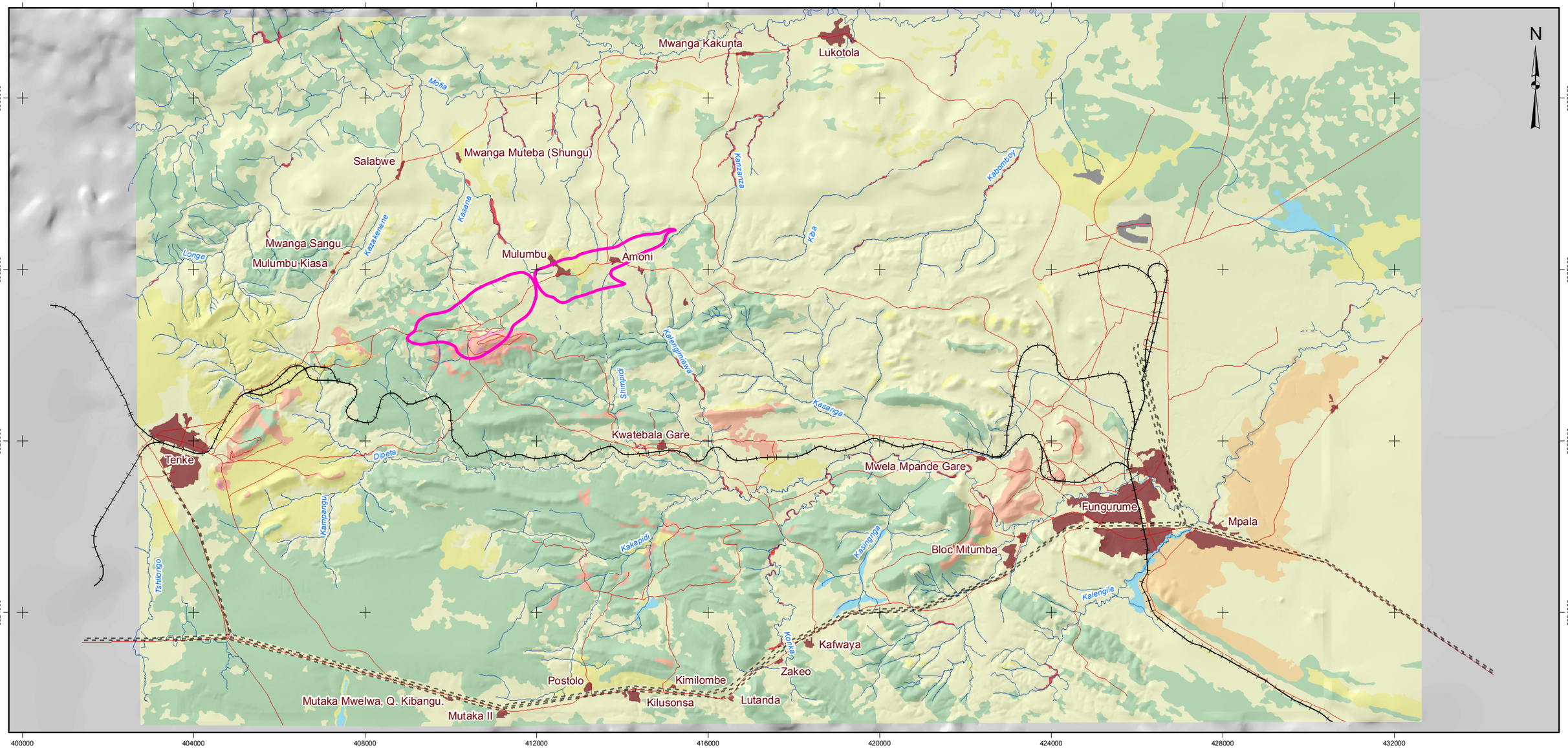
Groundwater

There could be impacts on the groundwater levels that underlie areas of gallery forest sustained by groundwater discharge (Section C2.10). The impacts will be progressive, gradually increasing over the duration of pit dewatering (from Year 8 onward) and then extend into the closure and post-closure period as the groundwater system re-establishes to a new equilibrium. The impacts would be greatest in the Kasana drainage north of the waste rock stockpile and similar north-flowing tributaries reaching the Mofia River in proximity to the mine.

Air Quality

Spatial modeling of air emissions has been conducted for the mine site over the life of the TFM project (see air quality, Section C2.8). 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 helps to take into account unforeseen events and uncertainties. Figure C3.1-5 shows the modeled results for annual average sulfur dioxide concentrations. No annual average nitrogen oxide ground-level concentrations above 30 micrograms per cubic meter will occur (Section C2.8).

The threshold level of sulfur dioxide at which concentrations affect sensitive flora, such as lichens, is 10 micrograms per cubic meter. This level of sulfur dioxide will be near to the mine area and approximately 91 hectares in size outside of the project footprint and inside the LSA (Table C3.1-6). Lichens primarily occur within the copper-cobalt outcrop vegetation type, which is not predicted to be impacted by SO_2.



LÉGENDE / LEGEND

- SO_2 ANNUEL / ANNUAL SO_2 (10 µg/m³)
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ROUTE / ROAD
- VOIE FERRÉE / RAILWAY

COUVERTURE VÉGÉTALE / UTILISATION DU TERRAIN / LANDCOVER

- AFFLEUREMENT ROCHEUX DE MINERAI CUIVRE-COBALT / COPPER-COBALT ROCK OUTCROP
- STEPPE-SAVANE SUR SUBSTRAT CUPRO-COBALTIFÈRE / COPPER-COBALT STEPPE-SAVANNA
- FORÊT DE MIOMBO / MIOMBO WOODLAND
- FORÊT DE MIOMBO DÉGRADÉE / MIOMBO WOODLAND DEGRADED
- FORÊT GALERIE / GALLERY FOREST
- ZONE HUMIDE / WETLAND
- MOSAÏQUE AGRICOLE / AGRICULTURAL MOSAIC
- ANCIENNE JACHÈRE / OLD FALLOW FIELD
- AÉROPORT / AIRFIELD
- PERTURBATION / DISTURBANCE
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3

ÉCHELLE 1:90000 KILOMÈTRES
SCALE 1:90000 KILOMETERS

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

CONCENTRATIONS EN DIOXYDE DE SOUFRE MOYEN AU NIVEAU DE SOL / ANNUAL AVERAGE SULFUR DIOXIDE GROUND LEVEL CONCENTRATIONS

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	MR	10 Nov. 2006		
GIS / SIG	AC	07 Mar. 2007		
VÉRIFIÉ / CHECK	MR	07 Nov. 2006		
APPROUVÉ REVIEW	MR	07 Nov. 2006		

FIGURE: C3.1-5

Table C3.1-6 Vegetation Types Affected by Annual Average SO_2 Ground-Level Concentrations

Vegetation Type	SO_2 (10 µg/m^3)	
	Hectares	Percent
agricultural mosaic	72	0.8
copper-cobalt outcrop	0	0
copper-cobalt steppe savannah	0	0
gallery forest	0	0
miombo woodland	6	0.2
degraded miombo woodland	10	0.9
wetland	0	0
settlement	3	1.1
Total	**91**	**0.6**

Note: Areas are outside of the project footprint. Not included are 17 hectares of agricultural mosaic and 3 hectares of miombo woodland that are inside the SO_2 isopleth but outside the LSA.

Percent = percent affected of vegetation type within local study area.

SO_2 = sulfur dioxide.

µg/m^3 = micrograms per cubic meter.

Invasive Exotic and Native Nuisance Species

There is a potential for the spread of invasive exotic and native nuisance species (weedy species) within and adjacent to the TFM project's facilities and access roads. As vegetation is cleared during the construction phase, areas will become susceptible to invasion by weedy species due to full sun conditions and a lack of competitors.

Over the life of the mine, it is expected that if left unchecked, weedy species would invade cleared areas not occupied by project facilities (e.g., soil stockpiles) and along forest edges. However, with effective mitigation to control the establishment and propagation of weedy species there is no expected impact.

It is known that roads contribute to increases in the spread of exotic species (Trombulak and Frissell 2000). Vehicle traffic within the LSA will increase sharply as construction begins and will lessen during operations. Wind and vehicles provide a way to transport weeds from areas on and off site into new areas as they become cleared. Invasion of unwanted species into good-quality miombo woodland may result from the project, potentially reducing site-specific species diversity.

At first, 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 normal succession. In other cases, a species may simply choke out others, reducing diversity and limiting succession. Control measures are planned to remove non-native and weedy species following criteria in PS-6 (IFC 2006C) as soon as they are discovered if they are considered to be a

threat to native ecosystems in the area or if they limit the ability of reclaimed sites to progress through stages of natural succession.

Reclamation and Closure

Reclamation and closure of the project has a number of objectives (Section D5), including:

- Include the results of local consultation and priorities in establishing post-mining land uses.
- Return land, where feasible, to being ecologically and physically stable.
- Make land resistant to erosion.
- Improve aesthetic quality where feasible.
- Ensure public health and safety.

From a flora perspective, the reclamation and closure plan should also:

- Restore vegetation (including agriculture) to an equivalent pre-mining land capability over as large as reasonably possible and feasible portion of the mine site.
- Prevent invasion of exotic and native nuisance species.
- Provide conditions such that pre-mining levels of biodiversity may be reached, where feasible, over time.
- Physical stabilization.

Landfills, ore stockpiles, tailings storage facility and waste rock facilities will predominantly be reclaimed for erosion control. Minimal recontouring will be performed on some facilities, if required to meet safety or stability objectives. The land will be planted with fast-growing native species. The plants chosen will be able to provide soil stability to prevent wind and water erosion. This will cover about 826 hectares of land (Table C3.1-4).

Reclamation trials of the mine site will attempt to convert approximately five percent of the disturbed area back to copper-cobalt steppe-savannah for an anticipated increase of 17 hectares (Table C3.1-4). The processing plant site and future plant site expansion, limestone quarry, roads and soil stockpiles that currently exist as miombo woodland will be reclaimed to degraded miombo woodland where feasible, unless future stakeholder/community consultation yields a preferable post-mining land use. About 641 hectares will be reclaimed to degraded miombo woodland (a change from 805 hectares during operation to

1,446 hectares at closure: Table C3.1-4). Holes will be dug, filled with topsoil from soil stockpiles, and then planted with native miombo tree species. Native grass species will be planted across the rest of the area to reduce invasion by weedy species and prevent erosion (see Section D5 for more details). This area is expected to naturally regenerate and return to a miombo woodland vegetation community if left undisturbed over time. Areas within the reclaimed degraded miombo woodland will be identified for sustainability projects (Section C3.1.3.6).

The powerlines, pipelines and soil stockpiles currently used for agriculture will be returned to an agricultural mosaic vegetation community, unless future stakeholder/community consultation yields a preferable post-mining land use (for example, certain powerlines may be left in place). This will cover 309 hectares of land (Table C3.1-4). The net loss of this vegetation type will be 985 hectares. One hectare of disturbed gallery forest will be re-established within the LSA so that there is no net loss.

Impact Analysis

Clearing Activities

The residual impact classification of the TFM project on the loss of key plant communities caused by site clearing is negative in direction for key vegetation types. The impact ranges from negligible to high in magnitude and is local in geographic extent (Table C3.1-7). The effects are predicted to be medium to long-term in duration and either reversible or irreversible depending upon the plant community.

Whether effects on the copper-cobalt plant communities are considered irreversible or reversible is uncertain but will be evaluated in the protection program proposed in the BDAP. The ecological requirements for these types of ecosystems are complex and there is uncertainty that current technologies can replicate these complexities. The further research on ex situ conservation efforts proposed will reduce this uncertainty over time. A conservative classification results in high environmental consequences for the two copper-cobalt community types. However, habitat potentially classifiable as critical will be translocated to ecosystem reconstruction areas so there is no anticipated loss.

Table C3.1-7 Residual Impact Classification for Key Question FL-1

Plant Community	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FL-1: What effect will the project have on loss or alteration of plant communities and reduced species diversity?							
Clearing activities during construction and operation							
copper-cobalt rock outcrop	negative	high	local	medium-term	dependent on results of ex situ habitat conservation efforts	high	high
copper-cobalt steppe-savannah	negative	high	local	medium-term	depends on results of ex situ habitat conservation efforts	high	high
gallery forest	negative	low	local	medium-term	reversible	high	low
miombo woodland	negative	moderate	local	medium-term	reversible	high	moderate
wetland	negative	low	local	medium-term	irreversible	high	low
Soil quality and capabilities							
all key plant communities	negative	moderate	local	long-term	irreversible	high	moderate
Surface water hydrology							
gallery forest	negative	low	local	long-term	irreversible	high	low
Groundwater							
gallery forest	negative	low	local	long-term	reversible	high	low
Air quality							
all key plant communities	negative	negligible	local	medium-term	reversible	high	negligible
Non-native and unwanted plant species							
miombo woodland	negative	low	local	long-term	reversible	high	low
Reclamation and closure							
copper-cobalt rock outcrop	n/a	n/a	n/a	n/a	n/a	n/a	n/a
copper-cobalt steppe-savannah	positive	low	local	long-term	reversible	medium	low
gallery forest	positive	low	local	long-term	reversible	medium	low
miombo woodland degraded	positive	high	local	long-term	reversible	medium	moderate
wetland	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Recognizing the importance of conservation of copper-cobalt flora, TFM is proposing mitigation by ex situ conservation of habitat potentially classifiable as critical, along with associated flora, and by establishing two or more ecosystem reconstruction areas. Potentially suitable locations have been identified at Shadirandzoro, KF68 and Mwadinkomba due to the diversity of the flora and the lack of economically feasible ore content (Figure C3.1-2). Within constraints determined by future mine planning, PMRs will also be established near the open

pits at Fwaulu Hill (Figure C3.1-4) and Fungurume Hill V to preserve copper-cobalt flora in situ.

These strategies will partially off set the high environmental impact of site clearing activities on the copper-cobalt vegetation communities. With the successful implementation of the mitigation strategies, there is expected to be no significantly adverse impact to habitat potentially classifiable as critical in accordance with PS-6 (IFC 2006C).

A moderate environmental consequence is assessed for the miombo woodland. The gallery forest and wetland areas have a low environmental consequence. A wetland, approximately one hectare in size, will be lost within the project's footprint area. As described earlier, the value of this wetland is primarily socio-economic.

Soil Quality and Capabilities

The TFM project is expected to affect soils in the LSA. Soil removal and disturbance may cause changes in soil quality and productivity (see soil, Section C2.4) due to:

- Disrupted biochemical cycles.
- Loss of organic matter.
- Increased erosion.
- Compaction.
- Mixing of soil horizons and possible contamination.

Project activities may also result in the loss of unique soils on the copper hills. These changes to the soil in the LSA will have a negative impact of moderate magnitude on the vegetation associated with them. The duration will be long term, the geographical extent will be local within the LSA, the impact will be irreversible and the frequency will be high (it will affect plant growth continuously). The environmental consequence is considered to be moderate (Table C3.1-7).

Surface Water Hydrology

Residual effects from dewatering (removal of water) of the mine pit and the capture of drainage from areas potentially impacted by project activities (e.g., tailings storage facility, waste rock facility, plant site) are predicted to reduce dry season baseflows in the Kasana, Sokolwela and Shimpidi rivers by 65 to 90 percent based on the 15 year mitigated flow change model

(Section C2.11). No sedimentation impacts are expected and therefore changes to channel geomorphology are expected to be negligible. Gallery forest health along these rivers will be monitored. Augmentation of dry season baseflows by 15 liters per second for each of the three local rivers will be made using excess mine pit dewatering water, as available. Due to uncertainties as to whether this action will be effective through the mine life and post-closure, TFM will also restore equivalent areas of degraded gallery forest habitats within the concession (see below). Residual impacts to gallery forest are predicted to be low (Table C3.1-7).

Release of intercept dewatering water may be as high as 200 liters per second to each of the Kasana, Sokalwela and Shimpidi drainages (based on the upper range estimate of the groundwater sensitivity analysis (Appendix C2.10-I). This volume is within range of the storm flows in each of the three rivers. However, this is approximately double the wet season baseflows (Section B2.11). This could cause erosion if there are continuous flows at this level. Monitoring of river morphology will be undertaken monthly to determine if excessive erosion is taking place. If erosion is shown to be a problem, excess water will be piped to the Dipeta River or erosion-control measures will be implemented.

Groundwater

The residual impacts on groundwater resources in the local aquifers are negative in direction (Section C2.10). This is because groundwater levels will decline in response to pumping. This will potentially reduce the groundwater discharge to springs and surface water close to the water supply/dewatering wells during mine operations, and may also lower the water table near gallery forests within the anticipated cone of groundwater depression. The complexity of the groundwater modeling leaves some uncertainty as to the level of impact that will actually be experienced by the gallery forests with the anticipated cone of depression (Sections C2.10 and C3.1). TFM has committed to use mine pit dewatering water, when available in excess of process water makeup needs, to augment stream flows within the potentially affected stream segments of the Kasana, Sokalwela and Shimpidi, beginning in about 2016, when effects are first predicted to occur. However, it is not known whether this augmentation will be sufficient to maintain healthy gallery forests for the duration that the pit will be dewatered (18+ years), as well as during the extended post-closure period as the water table is recovering to near pre-mining conditions around Kwatebala Hill (Section C2.10). Therefore, although it is expected that the provision of excess pit dewatering water will largely mitigate potential impacts to the gallery forest habitat, the success of that effort is not guaranteed. In order to more confidently address this potential future loss, TFM will restore an equivalent amount (to that within the cone of depression) of existing disturbed habitat along a stream segment not significantly affected by pit dewatering. The location for this

restoration program has yet to be selected but several sites within the TFM mining concessions would benefit from this restoration. The restoration will have benefits for not only gallery forest but also for aquatic habitat. It will also serve to control stream bank erosion and sedimentation. This program will require participation of the local population living and/or working near these sites. TFM will work with nearby farmers to plant the trees and ensure that the riparian system is protected over the life of the mine. Benefits to farmers will include increased erosion control and provision of non-timber forest products, fresh water and fish habitat. The restoration program will be initiated early in the mine life, no later than the date pit dewatering commences at Kwatebala. Residual impacts to gallery forests associated with the water courses affected by groundwater are predicted to be low during operations (Table C3.1-7).

At closure, after mine flooding, groundwater levels will begin to recover to new equilibrium conditions. After a post-mining pit lake has developed and local water tables have reached equilibrium, there will likely be little long-term residual impact on groundwater resources.

Air Quality

Sulfur dioxide induced impacts on vegetation will affect approximately 91 hectares (0.6 percent) of land within the LSA but will not affect the copper-cobalt rock outcrop vegetation type that potentially contains rare lichens. Therefore, effects are predicted to be negligible (Table C3.1-7). No nitrogen oxide exceedances are expected.

Invasive Exotic and Native Nuisance Species

Over the life of the mine, weedy plant species could potentially invade cleared areas not occupied by TFM project facilities (e.g., the perimeters of the project infrastructure, stockpiles) and along forest edges. It is expected that these species will not take hold and spread with the proposed mitigation measures. It is believed that weedy species found within the LSA can be controlled through appropriate weed management practices during construction and operation of the mine. Mitigation of invasive exotic and native nuisance species will comply with PS-6 (IFC 2006c). Impacts will be reversible, the magnitude of impact will be low, the geographic extent regional, the duration long term and the environmental consequence low (Table C3.1-7).

Reclamation and Closure

Implementing the reclamation and closure plan is expected to reclaim some plant communities (Section D5). Although some copper-cobalt steppe-savannah will be reclaimed, it still has a high environmental consequence as reclaimed areas will be small and the rate of success will be determined during the reclamation

trials. The copper-cobalt rock outcrop also potentially has a high environmental consequence depending on the success of the ex situ conservation program (Table C3.1-7). The gallery forest to be lost (about one hectare of direct impact, plus the area of any gallery forests lost within the groundwater cone of depression) will be re-established, resulting in a low environmental consequence. Miombo woodland will not be reclaimed as the best that can be expected is to return land to a degraded woodland site. Land that will be reclaimed back to degraded miombo woodland may, if left undisturbed, return to miombo woodland over time. The wetland plant community has a low environmental consequence as only one wetland (about one hectare in size) will be impacted. No reclamation of this wetland is planned.

Prediction Confidence

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.
- Knowledge of the effectiveness of mitigation measures.

Some of the flora impact predictions are based on the spatial distribution of vegetation types within the project LSA. The baseline vegetation map was developed from a combination of satellite imagery interpretation and limited ground-truthing (field-checking), relative to the size of the LSA and RSA. While it is expected that a majority of the vegetation map units have been correctly classified, some uncertainty exists in satellite imagery interpretation of vegetation types because only a small portion of the map units were ground truthed. Also, some vegetation types such as gallery forests were difficult to map as they can occur in thin strips or pockets too small to delineate. Thus, the prediction confidence is rated as moderate to high for differentiating the vegetation types into distinct classes.

The effects of the TFM project on the loss of vegetation types were assessed conservatively. Although restoring biodiversity will be a target of rehabilitation, it has not been assumed that interventions at mine closure can achieve comparable levels of biodiversity to the pre-existing situation. As a conservative estimate it has been assumed that rehabilitation will achieve an ecologically-stable and non-eroding environment that is free, or with a minimal population, of weedy species. There is a high level of confidence that the assessment of the impact on long-term loss of habitat is conservative and represents a worst case.

With the implementation of all of the proposed mitigation measures, there is a moderate to high degree of confidence that any species of concern (presently known or unknown) occurring in the copper-cobalt floral complex will be conserved (Section C3.1.3.5 Key Question FL-2). There is a moderate degree of confidence that habitat potentially classifiable as critical will not be significantly adversely affected.

It should be noted that impacts to copper-cobalt flora and their host habitats have been occurring for over a century in the Zambian and Katangan copper belt. However the proposed BDAP program (Appendix D3.1-II) marks the first formal, science-based attempt at conservation of these species. 'Success stories' with previous attempts are therefore not going to be found, since previous attempts have either not been made or were not documented.

However one of the organisms of concern is a member of a worldwide genus, *Cheilanthes*, and major herbaria have conducted research and program attempts at its propagation. The results of these programs will feed information into the BDAP, which is an iterative program that will evolve considerably based on new data arising from both existing sources and results of the TFM field program. Finally, it should be noted that individual *Cheilanthes* ferns have been found colonizing disturbed areas in Kwatebala, a discovery that bodes well for the organism's intrinsic adaptive flexibility.

Despite the lack of previous experience with transplant and enhancement, tests of germination of other cobalt-copper species have been conducted in New Zealand (Palmerston North), South Africa (Amplats Ltd.), Australia (Melbourne) and Belgium (Gembloux). Results have been varied, though published results are scarce and deal mainly with copper and cobalt uptake by leaves of seedlings.

It is expected that the BDAP (Appendix D3.1-II) will increase greatly the scientific body of knowledge on copper-cobalt plant conservation.

Dry season baseflows in the Kasana, Sokalwela and Shimpidi rivers will be augmented by using pit dewatering water, as available. The effects of varying degrees of reduced stream flow on gallery forest are not well known. The level of confidence is moderate for the assessment of the mitigated effects on baseflow. The level of confidence in being able to restore presently degraded gallery forests, as mitigation for the potential loss of gallery forests near the proposed mine, is moderate.

The impact predictions regarding impacts to groundwater resources are subject to some uncertainty because of the sensitivity of the model results to the interpreted

geological conditions. The major source of uncertainty is the nature and extent of low-permeability units at the mine and their interaction with surface water and springs. The level of confidence is moderate for the assessment of the mitigated effects on groundwater levels.

The level of confidence in the predicted effects of sulfur dioxide and nitrogen oxides on plants is low. Nevertheless, the values set out in these guidelines are conservative. This provides a reasonable assurance that the study is not under-predicting.

Monitoring

Monitoring programs will be implemented to ensure that the protection systems function effectively (Section D3.1.12). These programs will include:

- Monitor the PMRs to ensure survival of the plant communities.
- Monitoring of translocated/reconstructed sites and any reclaimed areas to ensure that habitat for species of concern becomes well established.
- Monitor the effectiveness of control measures for invasive exotic and native nuisance species within topsoil stockpiles, reclaimed areas, along the edges of miombo woodland where such species may encroach, and other areas where weeds may invade.
- Monitor gallery forest vegetation in the Kasana, Sokalwela and Shimpidi river drainages and, if significant impacts are detected, change the augmention of dry season baseflow using pit dewatering water as available.
- Monitor the restored gallery forest sites, used as compensatory mitigation for the potential loss of gallery forests due to a lowered groundwater table.
- Monitor river morphology and erosion levels monthly to determine if excessive erosion is taking place.
- Monitor the effectiveness of reclamation to ensure that minimum standards are achieved.
- Monitor dust deposition in representative areas of vegetation within the area of influence of the mining and plant operations.

C3.1.3.5 Key Question FL-2

Key question FL-2 is: Will the project increase the risk of loss of plant species (species extirpation or extinction)?

Within the miombo woodland there are outcroppings of copper and cobalt enriched rocks and metalliferous soil. Flora has developed in these areas capable of surviving these toxic soil conditions. Many of these plant species are endemic to the region.

Loss of habitat results in reduced plant population sizes and distribution ranges which increase the risk of extinction (Burkey 1995). Removing potentially classifiable critical habitat at the mine site during construction and operation phases may have an impact on plant species diversity. Without mitigation, removing potentially classifiable critical habitat could result in species elimination if populations are not found in areas other than those that will be mined.

Of greatest concern are the potentially critically endangered *Cheilanthes* sp. nov., *Chlorophytum* sp. nov. and *Faroa malaissei*, for which there are limited known records. Following the proposed mitigation of the project, there will be no loss of potential critical habitat, thus protecting the potentially critical endangered species. Without the project, artisanal mining would be resumed in an uncontrolled manner in the TFM concession, and habitat destruction that was previously occurring would ultimately result in species elimination. It is therefore be beneficial for the long-term survival of this species to have the project implemented along with the planned mitigation measures.

Following guidelines in IFC (2006c), there will be no loss of critical habitat within the LSA. Mitigation plans will protect all critical habitat within the project footprint resulting in no extirpation or extinction of species.

Linkage Evaluation

The copper-cobalt flora includes a rare group of plants that have developed in response to the metalliferous soil conditions on the copper-cobalt deposits. Among these are *Cheilanthes* sp. nov., *Chlorophytum* sp. nov. and *Faroa malaissei* all with limited known distribution records (see Appendix B3.1-III). While it is likely that the plants occur elsewhere in the region on copper-cobalt deposits that have not been intensively surveyed, this cannot be assumed without further investigation. Without proper mitigation and/or identification in future plant surveys (both of which are being conducted at the site), it is possible that mining could result in the elimination of a species. The linkage to loss of plant species is valid (Figure C3.1-1).

Assessment Methods

Professional judgment has been used to assess the probability of species losses, taking into consideration the flora surveys and associated research that was completed as a part of the baseline investigation for the ESIA. The IUCN has yet to analyze data on flora within the project area and has not made formal determination on individual species. For the purposes of this study, the ESIA team rated the potential conservation status of flora species based on existing data on population size, reduced extent of occurrence and/or area of occupancy, assuming application of the IUCN criteria (Section B3.1). Using these potential statuses as a conservative approach, it is considered possible that without proper mitigation, the TFM project could cause local eliminations of plant species populations that are potentially classifiable as critically endangered.

Mitigation

Efforts to minimize impacts on threatened species will be directed at protecting a proportion of the native environments of copper-cobalt flora, since mining activities are located in the same place that the threatened plant species occur. Mitigation measures have been designed to achieve no net loss of biodiversity or critical habitat where feasible. These measures are outlined in the strategies for the conservation of copper-cobalt flora (Appendix D3.1-I) and the biological diversity action plan (D3.1-II). For those sites containing copper-cobalt flora, it will be necessary to consider alternative conservation strategies, including the establishment of copper-cobalt collections in seed banks, botanical gardens and ecosystem reconstruction areas (ex situ conservation).

Specifically, the proposed mitigation measures will be as follows:

- Avoid unnecessary disturbance to copper-cobalt flora community types.
- Set aside two areas for ecosystem translocation/reconstruction, with precise locations yet to be determined, but likely to include mineralized areas identified in the Dipeta syncline (Figure C3.1-2).
- Set aside and protect smaller PMRs. These areas will be located in areas not affected by the short-term footprint of the project, or not disturbed in the short-term. PMRs will act to protect copper-cobalt flora from disturbance and to provide opportunities for seed collection and population monitoring. Several potential copper-cobalt PMRs have been identified at Fwaulu (Figure C3.1-4), parts of Fungurume Hill V and other hills in the TFM concession. Any area designated as a PMR will be protected against random damage by public and mine-fleet vehicles, until the PMR designation is removed.

- Protect and conserve flora species of concern in areas beyond the immediate project footprint but within areas of influence (e.g., copper-cobalt flora on land adjacent to the mine that will not to be stripped).
- Improve scientific knowledge of the occurrence and range of copper-cobalt flora by continuing the flora surveys on the hills within the LSA and extending them to copper-cobalt hills in the RSA and concession area.
- Develop a copper-cobalt flora ecosystem reconstruction program to promote the health of copper-cobalt flora during and after mining activities.
- Translocate potentially critical habitat and species of concern from the Kwatebala Hill to suitable ecosystem reconstruction sites in area(s) yet to be determined, but likely to include one or more areas shown in Figure C3.1-2 using plants and habitat (rocky substrate, blocks of turf, mineralized soil) removed from the mine site.
- Collect plants, seeds and other propagation material from the project footprint for use in the establishment of trials for cultivating species at designated locations.
- As feasibility is established during the current research program, include copper-cobalt flora and indigenous vegetation in reclamation and revegetation programs during operations and after closure.
- Set aside conservation areas, with an aggregate equivalent conservation value as Fungurume-V, with sites to be determined, once further botanical and geological investigations within the concession area are completed. Decisions on the type and duration of conservation use to which copper-cobalt flora hills such as Fungurume Hill V would be dedicated will be made with input from botanical experts.
- Educate the public on the importance of biodiversity and the copper-cobalt flora.
- Provide support for capacity building at the University of Lubumbashi for work on copper-cobalt flora conservation.

Many plant species can be successfully grown outside of their natural ecosystems under the right conditions. It is difficult, however, to guarantee that a species will survive and reproduce for multiple generations under artificial circumstances. Where there is a lack of knowledge about the physiological requirements of the species (as is the case for the copper-cobalt flora), the risks are increased. The copper-cobalt plant species responses to metalliferous soil concentrations and mycorrhizal fungi (fungi that form associates with plant roots) dependencies are unknown. For these reasons, the mitigation measures described above include both in situ and ex situ conservation approaches.

A further strategy that will be used is the relocation of threatened populations to reconstructed sites. Mining activities produce large amounts of waste rock with relatively low-grade mineral content. Such deposits might be used to recreate artificial hills on which copper-cobalt ecosystems could be reconstructed. Such sites may be re-colonized either by moving entire pieces of ecosystems (using construction equipment from the mining activities), by sowing seeds from natural sites, or by planting species grown in a botanical garden.

The action plan for the conservation of copper-cobalt flora (Appendix D3.1-I) and the biological diversity action plan (Appendix D3.1-II) provides more details about the proposed mitigation measures.

Results

The IUCN has yet to study data on the rare flora of the LSA and therefore has not listed any of these species in terms of a formal conservation/threat status. There are a total of 12 species that were listed as potential IUCN equivalent species of concern (Section B3.1) within the LSA (Table C3.1-8). Nine of these species will be directly affected by the TFM project. Three of these meet the potential status of critically endangered due to limited known distributions, as summarized below:

- *Cheilanthes* sp. nov. is a new species to science as it has so far only been found on Kwatebala Hill and Pumpi Hill XI, as well as historically at two other mine sites in Katanga where habitat has been totally destroyed
- *Chlorophytum* sp. nov. has only been recently identified as a potentially new species from collections made on Kwatebala Hill.
- *Faroa malaissei* has currently only been identified on Kwatebala, Fungurume Hill V, Goma and Pumpi.

Further studies will assess the distribution of this species and may change the ranking. Other species listed have very limited population sizes or distributions. Other species of concern not yet identified may also exist within the LSA. Additional identification of plant samples from previous field visits and further studies of copper hills in the area will be conducted during construction and operations.

Table C3.1-8 Species of Concern in the TFM Concession Area

Potential Status IUCN Equivalent Rank[a]	Species [b]	Occurring within Potential Critical Habitat
critically endangered	*Cheilanthes* sp. nov. [c]	yes
	Chlorophytum sp. nov. [d]	yes
	Aeollanthus saxatilis	yes[e]
	Faroa malaissei	yes
endangered	*Basananthe kisimbae*	no
	Barleria lobelioides	no
vulnerable	*Wahlenbergia verbascoides*	no
	Monadenium cupricola	no[a]
	Euphorbia fanshawei	no[a]
lower risk	*Haumaniastrum robertii*	no
	Triumfetta likasiensis	no
	Pellaea pectiniformis var. *nana*	no

[a] The IUCN has yet to analyze data on flora within the project area and has not made formal determination on individual species. For the purposes of the baseline study, the ESIA team has rated the potential conservation status of flora species based on existing data on population size, reduced extent.

[b] For locations see Appendix B3.1-III, Attachment I.

[c] Surveys conducted in November 2006 found this taxa to the west of the LSA.

[d] *Chlorophytum* sp. nov. was only discovered during the November 2006 surveys. The critically endangered ranking is temporary until further surveys can confirm the distribution of this species.

[e] Not affected by project.

Impact Analysis

Implementation of the proposed mitigation measures will ensure that species of concern occurring in the copper-cobalt flora are conserved and that their conservation status does not worsen. Mitigation measures will also ensure that any highly threatened or previously unidentified species that may not have been found to date will also be identified and conserved. The magnitude of the impacts under mitigated conditions is expected to be low, the geographical extent of the impact will be local to the LSA, impacts will be irreversible and duration will be long term. The environmental consequence for loss of plant species is low (Table C3.1-9).

Table C3.1-9 Residual Impact Classification for FL-2

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FL-2: Will the project increase the risk of loss of plant species (species extirpation or extinction)?						
negative	low	local	long-term	irreversible	medium	low

Prediction Confidence

The risk of species loss (extirpation or extinction) caused by the TFM project will depend on two factors: whether the plants are present only in areas that will be mined and the success of mitigation efforts. Additional data are necessary to more accurately define the risk. The limited occurrence of *Cheilanthes* sp. nov., *Chlorophytum* sp. nov. and *Faroa malaissei* suggests that they may be geographically restricted in the LSA. If this is the case, the risk would be high without proper mitigation. Alternatively, the limited known occurrence of these three species could be the result of the lack of a comprehensive survey of copper-cobalt deposits elsewhere in the DRC and in Zambia. In addition, there could be other not yet identified rare species associated with the copper-cobalt plant complex.

Tests of germination of cobalt-copper species have been conducted in New Zealand (Palmerston North), South Africa (Amplats Ltd.), Australia (Melbourne) and Belgium (Gembloux). Results have varied from place to place. Results published are scarce and deal mainly with copper and cobalt uptake by leaves of seedlings. Mycorhize activities could play an important role. More research is needed both on mining sites and in laboratories for providing baseline information.

Without proper mitigation, the prediction confidence that copper-cobalt flora can be conserved is low. With the implementation of all of the proposed mitigation measures, there is a moderate to high degree of confidence that any threatened species (presently known or unknown) occurring in the copper-cobalt floral complex will be conserved. There is a moderate degree of confidence that potentially classifiable critical habitat will not be significantly adversely affected.

Monitoring

A vegetation monitoring program will be implemented to ensure that protection of vegetation health and survival is being achieved (Section D3.1.12). This program will include:

- Monitoring the vegetation health of species in the proposed conservation areas to maximize their chances for continued survival.
- Monitoring the vegetation health of species in the copper-cobalt hill proposed ecosystem reconstruction areas and botanical gardens to maximize their chances for continued survival.
- Monitoring the vegetation health of species in the PMRs to maximize their chances for continued survival.

- Monitoring species that have been transplanted to ex situ sites.
- Monitoring species that have been transplanted for reclamation.

C3.1.3.6 Key Question FL-3

Key question FL-3 is: How can the project reduce the rate of miombo woodland and gallery forest degradation?

Deforestation (clearing forests) is one of the most obvious and unsustainable impacts resulting from human settlement in the RSA. Large parts of the RSA, particularly in the north, have already been deforested. It is expected that this trend of clearing forests will continue or worsen if migration into the RSA occurs in response to the perceived opportunities brought by the TFM project. The opportunities for the project to positively impact miombo woodland and gallery forest conservation will depend on the success of efforts to reverse or minimize this deforestation trend.

Linkage Evaluation

The increased land clearing brought about by increasing population growth and the growing population's need for fuel and farming activities will have an adverse affect on the sustainability of miombo woodland and gallery forest in the RSA. If the TFM project can have a positive impact upon miombo woodland and gallery forest it will affect visual aesthetics, terrestrial and aquatic fauna, socio-economics and biodiversity. These positive impacts would be in addition to the replacement of gallery forest habitats planned to mitigate effects related to direct loss of gallery forest and changes in flows.

Assessment Methods

Assessment methods relied on professional experience in relation to the efforts of the conservation of miombo woodland and gallery forest.

Mitigation

Agroforestry

Agroforestry can be defined as "the deliberate growing of woody perennials on the same unit of land as agricultural crops and/or animals, either in some form of spatial mixture or sequence" (Nair 1993). This can be achieved through:

- Social forestry, which pursues social objectives through the delivery of benefits to local people.

- Community forestry, which is a form of social forestry based on communal lands.
- At the individual landowner level.

By increasing the intensity of land use in areas that are already disturbed (e.g., agricultural mosaic and degraded miombo woodland community types) agroforestry practices may help to conserve the remaining miombo woodland and gallery forest in the LSA and RSA.

An appropriate agroforestry system is very closely linked to its economic feasibility and must also respond to socio-cultural factors. The use of agroforestry practices for fuelwood production has been achieved by farmers on their own farm, or on communally or publicly owned lands around the world with varying degrees of success. Some of the failures in communal and social forestry projects have been rooted in misunderstandings about the responsibilities to maintain the seedlings and the rights to the eventual wood products. There have, however, been some remarkable successes in promoting tree planting by private farmers (Nair 1993).

The employment potential of cash crop tree farming, such as for charcoal production, is significant. For every job in the traditional charcoal production sector lost by sustainable production programs, 1.6 jobs in integrated tree farming for charcoal production could be created (UNDP 1987). By combining tree plantations with agricultural products there is the benefit of producing multiple products from the same parcel of land. As long as appropriate species are selected, harvesting can be year-round instead of only once or twice a year.

Provision of a sustainable source of charcoal and timber products would reduce the pressure that is presently on miombo woodland from over-harvesting.

Non-Timber Forest Products

Non-timber forest products (NTFP) include all biological materials, other than timber, that are taken from forests for human use (DeBeer and McDermott 2002). This may include foods, medicines, spices, essential oils, resins, latexes, ornamental plants, wildlife, fuelwood and other raw materials. Natural lands may be protected by providing alternatives to destructive land-use practices such as swidden agriculture (slash and burn). If the local population can see the economic value in miombo woodland and gallery forest there is greater motivation to preserve them. One method of achieving this is through the collection of NTFP.

Promotion of the commercial extraction of NTFP as a conservation strategy is based on the argument that forest conservation must be able to offer economic incentives to local rural people in order to counter the threat from destructive land use practices (Ticktin 2004). However, it is well documented that the collection of NTFP can have negative impacts on populations, communities and the ecosystem when unsustainable extraction rates occur (Ticktin 2004). This happens when the harvest rates exceed the capacity of forest populations to replace the resources that are extracted. To prevent this, education must emphasize the unsustainability of over-exploitation (overuse) of individual species.

Results

A range of factors will determine whether the proposed interventions described above will contribute to the conservation of miombo woodland and gallery forest in the RSA. TFM is considering a variety of options to promote socio-economic development in local communities around the LSA. Initiatives to plant commercial tree lots using agroforestry techniques and encouraging sustainable commercial harvesting of NTFP could be among the measures that are funded and encouraged. When these proposed programs are adopted by communities in the LSA and RSA and integrated into other social development programs, the current rate of loss of miombo woodland and gallery forest will slow down.

Impact Analysis

There are many uncertainties affecting the proposed conservation activities for miombo woodland and of gallery forest to forecast a positive change (reduction) in the existing rate of deforestation. At best, without more evidence confirming other social development initiatives and a better understanding of the numbers of people that could migrate into the area, the magnitude is considered to be low (Table C3.1-10).

Table C3.1-10 Summary of Sustainability Assessment for Flora

Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key question FL-3: How can the project reduce the rate of miombo woodland and gallery forest degradation?				
Agroforestry				
low	half the community	long-term	low	low
Non-timber forest products (NTFP)				
moderate	half the community	long-term	low	moderate

Prediction Confidence

It is unknown how receptive the local population would be in adopting new methods in land management and use. The success of an agroforestry project and the promotion of using non-timber forest products (NTFP) would be largely dependent upon non-governmental organizations (NGOs) working with the communities. A key to success would be the support and involvement of village chiefs or key individuals within the community. The confidence in predicting the success of the sustainability initiatives is low, but the consequence of success justifies the effort and cost involved.

Monitoring

A monitoring and evaluation program will need to be developed and implemented once the exact nature and feasibility of the sustainability efforts are known. The monitoring program will need to assess the success and effectiveness of the proposed sustainability programs. The factors that should be considered in the monitoring program include:

- Areas under forest.
- Number of individuals or communities participating in the agroforestry program.
- Success of individual versus socially based agroforestry programs, if both are used.

The key indicator of success, which is a reduction in the rate of loss of miombo woodland and gallery forest in the RSA, can be monitored through annual analysis of satellite imagery.

C3.1.4 Cumulative Effects Assessment

There is a possibility that mine production for the project may expand from 115,000 to 400,000 tonnes per year of copper in the future. The cumulative case considers mining of the limestone quarry and other deposits in the TFM project concession area such as the Fungurume ore body. The current project proposal together with the expansion to 400,000 tonnes per year is termed the “expanded project.”

Key Questions

The expanded project is anticipated to result in changes to flora from construction, operation and closure activities of the mine. The key questions

relating to the cumulative effects of these activities on flora assesses changes at the community and species level (Table C3.1-11).

Table C3.1-11 Key Questions for Cumulative Effects on Flora

Impact Assessment	
Key question $FL_{(ce)}$-1:	To what extent will the project result in loss or alteration of plant communities and reduced species diversity?
Key question $FL_{(ce)}$-2:	Will the project increase the risk of loss of plant species (species extirpation or extinction)?

Note: ce = cumulative effects.

Linkage Evaluation

The expanded project would increase the disturbance footprint with the addition of facilities and expansion of others. The construction, operation and closure along with related project components would result in a loss or alteration of plant communities or species diversity and potential loss of plant species. These impacts would affect visual aesthetics, land use, terrestrial and aquatic fauna, socio-economics and biodiversity.

Assessment Methods

Detailed plans for the additional development of the expanded project are not yet available. The same general principles used to develop the mitigation recommendations for the current project proposal were used to develop the expansion scenario. The best available knowledge was used to determine the size and scope of the expanded project which was then mapped (Figure A4.17-1).

Mitigation

More intensive mitigation measures would need to be taken with the expanded project. The expanded project would result in the mining of additional copper hills, thereby increasing the potential loss of copper-cobalt flora. Mitigation for protection of the species of concern would include:

- Creation of larger management areas within the concession's copper flora ecosystems.
- Additional study into the physiological requirements for individual species.
- Intensive seed collections and transplantations from disturbed sites to protected areas.

Reclamation of disturbed areas would be required, as practical and feasible, to reinstate copper-cobalt flora on some hills.

Results

This expansion will result in the projected disturbance to vegetation types shown in Table C3.1-12.

Table C3.1-12 Estimated Areas Lost Due to Expanded Footprint (Includes Project Case)

Vegetation Type	Regional Study Area	Cumulative Effects Assessment	Land Cover Loss
	Hectares at Baseline	Hectares Lost	Percent Lost
agricultural mosaic	29,318	1,644	6
copper-cobalt rock outcrop	11	5	47
copper-cobalt steppe-savannah	598	231	39
disturbance	596	9	2
gallery forest	118	1	1
miombo woodland	14,794	738	5
miombo woodland degraded	2,890	444	15
old fallow field	994	0	0
wetland	147	1	0
Total	**49,466**	**3,088**	**6**

Impact Analysis

The expanded project is expected to have a negative impact upon all key plant community types (Table C3.1-13). The impacts will have the greatest negative effects on the copper-cobalt community types and will have a high environmental consequence. Other vegetation types are predicted to have a low environmental consequence. The environmental consequence was not calculated for the agricultural mosaic or the degraded miombo woodland as they are already highly disturbed areas.

Air quality parameters will have a negative impact upon key plant communities but will have a low environmental consequence. SO_2 at 10 micrograms per cubic meter will affect less than 10 percent of the copper-cobalt rock outcrops which may affect sensitive vegetation such as the lichens found on these outcroppings.

Table C3.1-13 Residual Impact Classification for Cumulative Effects Case

Plant Community	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question $FL_{(ce)}$-1: To what extent will the project result in loss or alteration of plant communities and reduced species diversity?							
Clearing activities during construction and operation							
copper-cobalt rock outcrop	negative	high	local	long-term	depending on results of ex situ habitat conservation efforts	high	high
copper-cobalt steppe-savannah	negative	high	local	long-term	depending on results of ex situ habitat conservation efforts	high	high
gallery forest	negative	low	local	long-term	reversible	high	low
miombo woodland	negative	low	local	long-term	reversible	high	low
wetland	negative	low	local	long-term	irreversible	high	low
Air quality							
all key plant communities	negative	low	local	medium-term	reversible	high	low
Key Question $FL_{(ce)}$-2: Will the project increase the risk of loss of plant species (species extirpation or extinction)?							
all key plant communities	negative	low	regional	long-term	irreversible	medium	moderate

The loss of vegetation due to clearing of land for the expanded project will have the greatest impact upon the key vegetation community types. Disturbances will affect 82 percent of the copper-cobalt rock outcrops, 39 percent of the copper-cobalt steppe-savannah and five percent of the miombo woodland community type.

These consequences are based on impacts within the RSA and may not accurately reflect impacts within the LSA. The risk of loss of threatened plant species will only be low if mitigation is well developed and implemented to protect copper-cobalt flora populations.

Prediction Confidence

The risk of species loss caused by the TFM project will depend on the probability of impacting on plants with highly restricted geographic distributions. This risk is poorly known at present. Under the unmitigated mining scenario, the prediction confidence about impacts on copper-cobalt floral elimination is low. However, with the implementation of all of the proposed mitigation measures, there is a moderate to high degree of confidence that any threatened species (presently known or unknown) occurring in the copper-cobalt floral complex will be conserved.

C3.1.5 Conclusions

The impacts upon the loss or alteration of plant communities and reduced species diversity ranges from low to high depending on the impact and community type (Table C3.1-14). The greatest impacts will occur to the copper-cobalt flora from site clearing during the construction and operation phases. There are no expected losses of species (species extinction) or species extirpation with successful implementation of the mitigation plan. However, there is a high uncertainty regarding aspects of the potential effects of the project on species loss resulting in a moderate prediction confidence.

Table C3.1-14 Summary of Residual Effects to Vegetation

Plant Community	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FL-1: To what extent will the project result in loss or alteration of plant communities and reduced species diversity?							
Clearing activities during construction and operation							
copper-cobalt rock outcrop	negative	high	local	medium-term	depending on results of ex situ habitat conservation efforts	high	high
copper-cobalt steppe-savannah	negative	high	local	medium-term	depending on results of ex situ habitat conservation efforts	high	high
gallery forest	negative	low	local	medium-term	reversible	high	low
miombo woodland	negative	moderate	local	medium-term	reversible	high	moderate
wetland	negative	low	local	medium-term	irreversible	high	low
Soil quality and capabilities							
all key plant communities	negative	moderate	local	long-term	irreversible	high	moderate
Hydrology							
gallery forest	negative	low	local	long-term	irreversible	high	low
Groundwater							
gallery forest	negative	low	local	long-term	reversible	high	low
Air quality							
all key plant communities	negative	negligible	local	medium-term	reversible	high	negligible
Non-native and unwanted plant species							
miombo woodland	negative	low	local	long-term	reversible	high	low
Closure and reclamation							
copper-cobalt rock outcrop	n/a	n/a	n/a	n/a	n/a	n/a	n/a
copper-cobalt steppe-savannah	positive	low	local	long-term	reversible	medium	low
gallery forest	positive	low	local	long-term	reversible	medium	low
miombo woodland	positive	high	local	long-term	reversible	medium	moderate
wetland	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Key question FL-2: Will the project increase the risk of loss of plant species (species extirpation or extinction)?							
all key plant communities	negative	low	local	long-term	irreversible	medium	low

n/a = Not applicable (neutral impacts not classified).

Long-term sustainability plans have been developed involving the creation of agroforestry and extraction of NTFP (Section C3.1.3.6). Outcomes for the adoption of agroforestry practices would:

- Intensify land-use on already disturbed land, with the expected result of reducing swidden agriculture.
- Maintaining or reducing the rate of native miombo and gallery forest degradation under increasing pressure from an expanding population.

Using NTFP gives native communities, such as miombo woodland and gallery forest, an economic value to the local population (Table C3.1-15).

Table C3.1-15 Summary of Sustainability Assessment for Flora

Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key question FL-3: How can the project reduce the rate of miombo and gallery forest degradation?				
Agroforestry				
low	half the community	long-term	low	low
Non-timber forest products				
moderate	half the community	long-term	low	moderate

The cumulative effects assessment (Section C3.1.4) looked at the impacts of an expanded project increasing copper production from 115,000 to 400,000 tonnes per year. This would considerably increase the TFM project's footprint area which would have low to high environmental consequences on plant communities (Table C3.1-16). The greatest potential risk from the expanded project is on vulnerable plant species. The expanded project will increase development of the copper hills and increase the potential for species loss if mitigation is not successful.

Table C3.1-16 Residual Impact Classification for Cumulative Effects Case

Plant Community	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question $FL_{(ce)}$-1: To what extent will the project result in loss or alteration of plant communities and reduced species diversity?							
copper-cobalt rock outcrop	negative	high	local	long-term	depending on results of ex situ habitat conservation efforts	high	high
copper-cobalt steppe-savannah	negative	high	local	long-term	depending on results of ex situ habitat conservation efforts	high	high
gallery forest	negative	low	local	long-term	reversible	high	low
miombo woodland	negative	low	local	long-term	reversible	high	low
wetlands	negative	low	local	long-term	irreversible	high	low
Key question $FL_{(ce)}$-2: Will the project increase the risk of loss of plant species (species extirpation or extinction)?							
all key plant communities	negative	low	regional	long-term	irreversible	medium	moderate

C3.2 FAUNA

C3.2.1 Introduction

This section presents the environmental impacts assessed for the effects of the Tenke Fungurume Mining (TFM) project on fauna (animal life). The information presented meets the requirements of the TFM project's terms of reference (Appendix E8) and includes details on:

- Components within each phase of the project that may influence or affect the local fauna.
- Concerns identified by stakeholders and regulators.
- Proposed mitigation measures to minimize impact on the fauna of the area.
- Impact assessment (using qualitative and quantitative methods) for potential impacts of the project on all the faunal assemblages within the study areas.
- Sustainability assessment for key faunal issues.
- The monitoring program that will be used to identify and monitor project impacts on the fauna of the area.

The TFM project will involve the extraction of copper-cobalt ore deposits in the Tenke Fungurume concession area at the Kwatebala, Goma and Fwaulu hills. Development of the mine will involve varying degrees of land disturbance, such as removal of vegetation, excavation and ground compaction.

Existing habitat types in the Local Study Area (LSA) with the associated faunal assemblages that will be influenced are described in the fauna baseline report (Section B3.2).

This section is organized as follows:

- Section C3.2.2 describes the study areas.
- Section C3.2.3 describes the impact assessment approach and results.
- Section C3.2.4 provides the cumulative effects assessment.
- Section C3.2.5 discusses the conclusions of the assessment.

A glossary of terms and acronyms used in this section is provided at the back of this volume.

C3.2.2 Study Areas

The baseline Regional Study Area (RSA) and Local Study Area (LSA) are the same study areas that were used in the fauna baseline report, (Figure C1.6-1). The RSA encompasses all proposed facilities for both the proposed project and its potential future expansion plans to produce 400,000 tonnes per year of copper. The LSA contains a representative cross section of all of the habitats that occur in the mining concession.

The mining of the Kwatebala, Goma and Fwaulu hills will mainly take place on the crests and mid-slopes of the copper-cobalt rock outcrop habitat. The waste rock facilities, tailings storage facilities and the processing plant will mainly be situated in old fallow lands (agricultural mosaic) and miombo woodland. The limestone quarry will influence the crest and mid-slope of a hill in miombo woodland. The construction camp and permanent village will be situated mostly in degraded miombo woodland (Figure C1.6-1).

C3.2.3 Impact Assessment

C3.2.3.1 Issue Scoping

Baseline studies (Section B3.2) indicated that fauna within the RSA is very sparse due to conversion of land to agriculture and over hunting. Few large animals are present.

The TFM project has the potential to affect the residual indigenous (native) local fauna that remain after impacts from agriculture and over hunting as a result of activities described in Section A4 (Project Description). Issues related to fauna that are considered by the environmental and social impact assessment (ESIA) for the project include:

- Vegetation clearing for the construction of the mine, plant, buildings, roads, power lines and other infrastructure.
- Covering of viable habitats with foreign material.
- Fencing and other obstructions inhibiting animal movement.
- Increased vehicle traffic creating a barrier to movement and causing road kills.
- Blasting and other noise nuisance during construction and operation.
- Dust produced during construction and operation.
- Discharge of treated sewage effluent.

- Accidental and off-specification releases and spills.
- The increase in people taking up permanent residence, which will result in more clearing of indigenous vegetation, degradation of habitats, hunting and harassment of wild animals.

Sustainability issues related to the fauna of the area include:

- Site reclamation and closure activities.
- The increase in people taking up permanent residence, which will result in more clearing of indigenous vegetation and degradation of habitats.

Issues relating to fauna noted during the public consultation process (Section A6 and E6) include many of those noted above. In addition, concerns were expressed that:

- Snakes and other poisonous animals will move into areas where people reside once the mine is constructed and the tailings storage facility fills up.
- A nature conservation area in the concession would be useful to protect plants and animals (Section E6).
- Population of animals that are presently in the area may be reduced and that this would affect people who presently consume these animals.

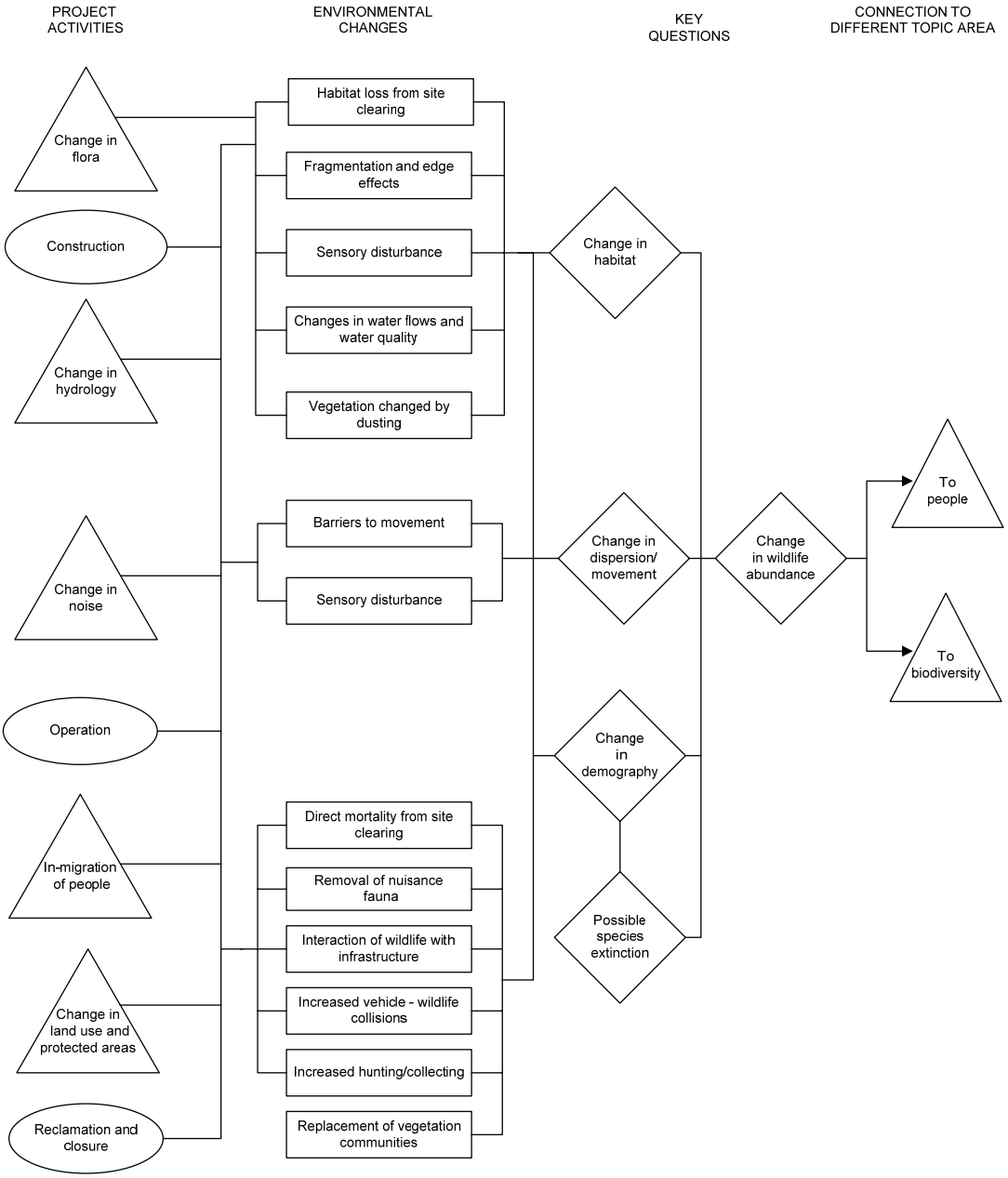
C3.2.3.2 Key Questions and Indicators

The linkages shown in Figure C3.2-1 were assessed by answering key questions for fauna (Table C3.2-1). The use of linkage analysis and key questions is described in Section A5.

Table C3.2-1 Key Questions for Fauna

Impact Assessment
FA-1: What effect will the project have on fauna habitat?
FA-2: What effect will the project have on fauna dispersion and movement?
FA-3: What effect will the project have on fauna demography?
FA-4: What influence will the project have on species extinction?
Sustainability Assessment
FA-5: How can the project have a positive effect on the habitats and associated fauna of the area?

Figure C3.2-1 Fauna Linkage Diagram



The Global Reporting Initiative (GRI 2005b) and International Federation of Consulting Engineers (FIDIC 2006) have identified indicators for ecosystems, biodiversity and natural habitats. Table C3.2-2 provides a description of these indicators and how these have been adapted for use in the environmental and social impact assessment (ESIA). In some cases, the indicators are discussed in other parts of the ESIA, as listed in the third column of Table C3.2-2. In the other cases, indicators specific for fauna are used to assess impacts in this section.

Table C3.2-2 Indicators for Fauna

GRI Indicators [a]		FIDIC Indicators		ESIA Indicators
EN20	water sources and related ecosystems/habitats significantly affected by use of water			effect of change in hydrology on habitat (see Section C3.1)
EN26	changes to natural habitats resulting from activities and operations and percentage of habitat protected or restored	EN16	proportion of area affected by the project that contains key ecosystems	area of each habitat type disturbed each year (see Section C3.1) area of each habitat reclaimed each year (see Section C3.1)
EN7	description of the major impacts on biodiversity associated with activities and/or products and services in terrestrial, freshwater, and marine environments			terrestrial biodiversity addressed in Section C3.4 and aquatic biodiversity addressed in Section C3.3
EN28	number of IUCN Red List [b] species with habitats in areas affected by operations	EN17	measurements of effect of project on the abundance of key species	predicted influence on IUCN Red List fauna or key species expected to be present in the influenced habitats of the RSA
EN29	business units currently operating or planning operations in or around protected or sensitive areas			predicted influence on fauna expected to be present in the copper-cobalt and wetland habitats of the LSA, based on areas of habitat affected
EN34	significant environmental impacts of transportation used for logistical purposes			predicted influence on fauna (traffic related faunal mortality) expected to be present in the influenced habitats of the RSA traffic/transport disclosed in Section C2.13

[a] Global Reporting Initiative (GRI 2005), International Federation of Consulting Engineers (FIDIC 2006).

[b] World Conservation Union (IUCN 2001).

C3.2.3.3 Assessment Criteria

Table C3.2-3 provides the impact description criteria used to quantify changes in indicators as described in the ESIA methods of Volume A. The screening system for sustainability consequence is provided in Section A5.

Table C3.2-3 Impact Description Criteria for Fauna

Direction[a]	Magnitude[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
positive, negative or neutral for the criteria measured	**negligible:** no measurable effect **low:** <10% change in the criteria measured **moderate:** 10 to 20% change in the criteria measured **high:** >20% change in the criteria measured	**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 20 years **long term:** >20 years	reversible or irreversible	**low:** occurs once or rarely **medium:** occurs intermittently **high:** occurs continuously

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

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

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

(d) Duration: length of time over which the environmental effects occurs. Considers a two-year construction period and a 20-year operations period.

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

(f) Frequency: how often the impact occurs.

C3.2.3.4 Key Question FA-1

Key question FA-1 is: What effect will the project have on fauna habitat?

Linkage Evaluation

Figure C3.2-1 shows the linkage between project activities and potential effects. The linkages associated with key question FA-1 are described in this section. Potential effects on fauna could occur during all phases of the project, including construction, operations, closure and post-closure. The key questions used to guide this assessment are also shown.

Habitat Loss Due To Site Clearing

Direct loss of faunal habitat through clearing of vegetation during site preparation will influence extensive tracts of land. Affected areas include both previously modified and natural lands. A large component of this cleared land will be covered by new material, changing any underlying habitat permanently. This linkage is discussed below.

Open mine pits: The potential effects of the removal of copper-cobalt flora habitat is discussed in detailed on Section C3.1. However, the surfaces of the mineralized hills have previously been disturbed by extensive artisanal mining operations. These disturbances include trenches and pits.

Ore stockpiles and waste rock: Low-grade ore stockpiles will be situated primarily to the west of the processing plant. The waste rock facility will be established immediately north of the tailings storage facility and west and north of the processing plant. Preparation of the ore stockpile and waste rock facilities

will involve vegetation clearance, topsoil salvage, construction of access roads, and construction of storm ditches and culverts to direct water away from the facilities.

Tailings storage facilities (TSF): The Kwatebala TSF will be directly southwest of the processing plant site. The facility is presently designed to store about 115 million tonnes of tailings.

If necessary, another TSF will be built north of Fungurume which would occupy about 250 ha.

Return water dam: Initially, this water storage facility will be within the limits of the TSF. After the TSF has operated for about two years, the return water dam will be relocated immediately east of the TSF.

Processing plant site and associated infrastructure: The processing plant will be established just north of the Kwatebala pit and east of the TSF.

Powerline: A powerline will be extended from the national grid north of Fungurume to the plant site.

Employee accommodation: A camp for construction workers will be developed at a site north of Fungurume.

The area influenced by all these developments (Figure C1.6-1) is substantial. This linkage is considered valid.

Fragmentation and Edge Effects

The facilities included within the main mining development are located close together and will not fragment the LSA. Also, the area is already moderately fragmented by farming, roads and other activities of the local population. An increase of migrants to the area might result in an increase in fragmentation and edge effects. This linkage is considered valid.

Sensory Disturbance

Night operations will require large mobile light sources, including diesel-powered light plants. These unnatural light sources will increase light pollution of the area and will influence nocturnal (active at night) fauna and attract insects, especially during the rainy season.

Although there will be a constant background noise and intermittent louder noises due to routine mining and processing operations, most of the fauna grow used to this kind of disturbance and may tolerate it after a short while. However, conventional drill and blast methods during construction and operation will create a higher level of noise and vibration pulses. Sensitive fauna in the area will be influenced, including nesting and breeding birds. This linkage is considered valid.

Changes in Water Flows and Water Quality

Changes in water flows will not influence most terrestrial biota (flora and fauna) directly. However amphibians that use riverine habitats will be affected should the quantity and quality of their breeding habitat change. During operations, TFM is committed to maintaining water quality and will not discharge effluent (waste) water that does not comply with applicable water guidelines.

Due to a combination of groundwater use, pit dewatering and change in surface infiltration rates, the project is expected to lower the water table underneath and proximal to the project site. This change in water table may reduce the base flows in three streams near the project site. The base flows are the stream flows derived from groundwater calculated based on a site-wide hydrologic model, calibrated with actual streamflow measurements (Section C2.11). The potentially affected streams are the Kasana, Shimpidi and Sokalwela. As a result, the linkage to changes in surface water flow and changes in water quantity available to fauna is considered valid.

Site preparation and clearing during the construction phase and construction of roads and facilities have the potential to result in increases in suspended sediment loadings and sedimentary-bound contaminants to receiving waterbodies. Also, the excess water from the mine pit may be released into nearby watercourses. This linkage regarding excess water and suspended sediment loads is considered valid.

Vegetation Changed by Dusting

Road activity is dependent on the production schedule. Construction activity will see high levels of highway transport equipment moving through the project area, as well as the movement of support equipment such as haul trucks, dozers, graders and front-end loaders.

If not adequately controlled, fugitive dust from mine traffic, ore stockpiles, the waste rock facility and the tailings facility may influence the vegetation of the area adversely (Section C3.1). Negative impacts on vegetation will reduce the presence of local fauna. With the expansion of the road network and an increase

in heavy vehicle traffic, more dusting of indigenous vegetation is expected along these routes and near the above-mentioned facilities. Due to the potential change in vegetation structure and faunal habitat, this linkage is considered valid.

Assessment Methods

Habitat Loss Due to Site Clearing

The LSA contains a representative cross section of all of the habitats that occur in the TFM project concession area. While field surveys were not conducted over the whole LSA, the findings of the baseline study may be used with confidence elsewhere in both the LSA and RSA. Transects were selected so as to provide a baseline that is representative of faunal diversity and species richness throughout the mining concession, without the need for further field survey.

Habitats within the LSA were mapped as part of the flora baseline (Section B3.1) and impacts on those habitats due to site clearing were assessed in the flora and biodiversity impact assessment sections (C3.1 and C3.4) by overlaying the project's footprint on the habitat types within a Geographical Information System (GIS) analysis. In this section, these impacts are discussed in the context of their effects on fauna.

Fragmentation and Edge Effects

Fragmentation and edge effect impact statistics are presented in the biodiversity impact assessment (Section C3.4). In this section, impacts to habitat edge are discussed in the context of their effects on key fauna indicators.

Sensory Disturbance

Sensory disturbance from light is assessed qualitatively for fauna. Noise levels were modeled using conservative assumptions and compared with baseline levels to determine potential impacts (Section C2.9). Noise exceeding noise criteria (Section A2.7) from the World Bank Group (45 A-weighted decibels [dBA] night and 55 dBA day, developed for assessing impacts to humans, are utilized to infer impacts to wildlife for the purposes of this assessment. The area extent of habitat types within the two modeled noise bands is calculated to determine the impacts (greater than 45 dBA and greater than 55 dBA). Information is drawn from other impact assessment sections to complete this analysis, including the traffic (C2.13) and noise (C2.9) sections.

Changes in Water Flows and Water Quality

The results of analyses in the sections for groundwater (C2-10), surface water hydrology (C2.11) and surface water quality and sediment (C2.12) are used in

this analysis to conduct a qualitative assessment of impacts on specific groups of fauna.

Vegetation Changed by Dusting

The effects of dust along the edge of project developments on adjacent habitats are analyzed in the flora section (C3.1). These effects are discussed qualitatively with respect to resulting impacts on fauna in this section.

Mitigation

Habitat Loss Due to Site Clearing

Mitigation measures that will reduce the effects of habitat loss and alteration from site clearing include:

- The analysis of alternatives (Section A3) has resulted in facility design modifications for the processing plant, tailings storage facility, construction camps and linear access routes aimed at reducing impacts. These included grouping facilities together to minimize impacts.
- During the final footprint layout, every effort must be made to minimize impacts on trees, rocky outcrops, copper-cobalt hills, flora and other habitat-providing structures. Such areas will be protected as plant micro-reserves (PMRs; Section D3.1.13).
- Avoid the covering of rocky outcrop habitats by foreign materials.
- Pipelines and powerlines will follow common corridors to minimize increased edge.
- Temporary, localized accommodation of workers in developed town areas and other land use planning measures will help to prevent the occupation of natural land with new homesteads that could be a socio-economic side-effect of the project's development.
- Provide 60 inch minimum horizontal separation on powerlines between energized conductors and/or energized conductors and grounded hardware (more distance if feasible to account for the possibility of larger birds).
- Insulate powerline hardware or conductors against simultaneous contact if adequate sparing is not possible.

Fragmentation and Edge Effects

Mitigation measures that will reduce the effects of fragmentation and edge effects include:

- Through the "analysis of alternatives" process (Section A3), the project elements were organized to reduce edge effects. For example, the processing plant, tailings storage facility and mine will be kept close together to reduce the length of access routes between them. This will contain the impact footprint within a smaller area, creating less edge effects.
- Pipelines and power lines will follow common corridors to minimize increased edge.
- Temporary, localized accommodation of workers in developed town areas and other land use planning measures will help to prevent the occupation of natural land with new homesteads that could be a socio-economic side-effect of the project's development.

Sensory Disturbance

Mitigation measures that will reduce the effects of impacts due to sensory disturbance include:

- Much of the actual mining will be conducted by a surface miner, which will reduce the need for explosives and for a primary crusher; both of which will reduce overall noise levels.
- Other means of mitigating noise impacts to reduce effects on fauna will include those being used to limit effects on people (Section C2.9).

Changes in Water Flows and Water Quality

Mitigation measures that will reduce the effects of impacts due to changes in water quantity and water quality are described in Section D3.1.5.

Impacts on Vegetation Changed by Dusting

Dust from the mine area roads will be minimized by the use of a 45-tonne capacity water truck. The water truck will operate both within the pit and along all waste and ore haul routes. It will also be used to cover other minor facility roads and the processing plant areas, as required.

Results

Habitat Loss Due to Site Clearing

The habitats (biotopes) in the LSA are unusual in a regional context due to the presence of copper-cobalt rock outcrop and copper-cobalt steppe-savannah habitats, which are rare within the region as a whole. The LSA also contains habitats that are regionally common, such as miombo woodland, agricultural mosaics and other areas already disturbed by human use. Table C3.2-4 lists the areas of disturbance in the LSA and RSA for some of the habitats found to be important for fauna.

Table C3.2-4 Habitat Changes Due to Site Clearing for Major Facilities

Habitat	Main Project Element Causing Disturbance	Change in Habitat Area (ha)	Percent Change of this Habitat in LSA	Percent Change of this Habitat In RSA	Faunal Species in this Habitat	% of Total Fauna	Red-Listed Species[a]
copper-cobalt rock outcrop	open mine pits	-5	-47	-47	93	5	none
copper-cobalt steppe-savannah	open mine pits waste rock/ore facilities	-185	-37	-31	104	5	none
miombo woodland (intact)	open mine pits waste rock/ore facilities, tailings facility, plant site/expansion construction village	-519	-16	-4	310	17	1 (short-eared trident bat)
corridors in developed areas disturbed areas/mosaic[b]	open mine pits waste rock/ore facilities, plant site/expansion	+1080	+11	+3	262	16	1 (short-eared trident bat)
gallery forest/riparian	waste rock/ore facilities	-1[c]	-3	-1	264	14	1 (otter shrew)
marsh wetland	plant sit/expansion	-1.3	-4	-1	164	9	0

[a] World Conservatory Union (IUCN 2001).

[b] Includes settlements clearings and agricultural mosaic.

[c] Does not include hydrologic impacts, which will be fully compensated for through restoration.

ha = hectares.

About half of the copper-cobalt rock outcrop habitat (47 percent) will be influenced intensively by the open pit mining. Of the 93 fauna species occurring on this habitat, no World Conservation Union (IUCN) Red-listed animals are expected. Most of these species can be found in other habitats and none is restricted to this rare habitat.

Thirty-seven percent of the copper-cobalt steppe-savannah will be affected in the LSA. No Red-listed fauna is known in this habitat.

The RSA contains a very large area of miombo woodland in comparison with the LSA, indicating the more common nature of miombo woodland regionally. Sixteen percent of miombo woodland habitat will be affected in the LSA. This habitat is important in that it supports a high diversity of fauna including one known Red-listed species, the short-eared trident bat (Table C3.2-4). This bat does not occur everywhere in the miombo forest. It has historically been documented in the RSA, but was not observed in the recent baseline study (Section B3.2).

Most of the other development where large-scale vegetation clearing will occur, will take place in habitats already influenced by local communities (corridors in developed areas and human-impacted areas). The largest structures, covering the biggest areas, are the waste rock and tailings storage facilities, which are planned in the human-impacted areas. The project will increase the proportion of such human-disturbed habitat types in the LSA by about 11 percent (Table C3.2-4).

Fragmentation and Edge Effects

The project will tend to increase habitat edge, especially disturbed edge. As described in Section C3.4, the project will increase the edge to area ratio of some habitat types, including the agricultural mosaic (plus 17 percent), degraded miombo woodland (plus 18 percent), and gallery (riparian) forest (plus one percent). The project will lower the edge-to-area ratio of both the copper-cobalt rock outcrops and the copper-cobalt steppe-savannah by 15 percent and will have a negligible effect on edge in other habitats.

Although the areas influenced by humans are lower in species richness, corridors left intact by existing land users remain valuable habitats to a large component of the local fauna. This continuous habitat is likely used by 262 species (14 percent of fauna) as temporary habitat and as a migration corridor. In general, newly created edge habitats will become important areas for fauna, although “core habitats” will tend to decline in size as patch sizes of most habitats decline (Section C3.4).

In addition to the direct effects of the project, an increase in human population might put pressure on surrounding habitats such as forests or fallow fields that are presently not used by people.

Sensory Disturbance

Noise levels were modeled using conservative assumptions and compared with baseline levels to determine potential impacts (Section C2.9). Noise is considered for the ESIA to also be an impact on fauna when it exceeds the 45 dBA criterion provided for assessing impacts to humans by the World Bank Group (1995a) (Section C2.9). Existing noise levels range from 27 to 62 dBA, depending on location and time of day (Section B2.9), with the high-end noise levels being along roads and in towns. A summary of the results of the noise impact model for Years 2010 and 2016 are presented in Table C3.2-5.

Table C3.2-5 Areas of Noise Impact at 45 dBA

Habitat Type	Area of Impact at Year 2010 (hectares)	Area of Impact at Year 2016 (hectares)
agricultural mosaic	478	442
copper-cobalt rock outcrop	1	0.3
copper-cobalt steppe-savannah	22	10
gallery forest	8	< 0.1
miombo woodland	129	49
miombo woodland degraded	41	24
old fallow field	0	0
wetland	0	0
Total	**688**	**534**

The extent of habitat types within the two modeled years is an indicator of the extent of impact due to noise. At year 2010, a total of 688 hectares of land surrounding the project (in addition to areas physically impacted by the project) will have noise levels elevated to at least 45 decibels. This represents five percent of the LSA. At year 2016, a total of 534 hectares of land surrounding the project will have noise levels elevated to at least 45 decibels. This represents four percent of the LSA. In both cases, the most impacted habitats are the agricultural mosaic and the miombo woodland.

The lighting associated with the project is likely to considerably increase the amount of lit area on a local level, due to the relative lack of large lit areas under baseline conditions. Lights cause insects to gather and can result in higher levels of predation by insectivores such as bats. Other fauna will avoid lit areas.

Changes in Water Flows and Water Quality

Changes to groundwater levels (Section C2.10), surface water volumes (Section C2.11) and in surface water and sediment quality (Section C2.12) may have a negative effect on some amphibian species.

Eighteen local frog species use the riverine environment as habitat and part of their life-cycle is completed in the aquatic environment of the river. Should the upper parts of the Sokalwela and Shimpidi catchments silt up and pools disappear, these frogs will move downstream to breed in areas containing pools.

The hydrology assessment predicted effects on flows for the first seven years of mining when no pit dewatering will take place, and the final years of mining when dewatering water, intercepted by boreholes, will be used as necessary to augment dry season flows in local streams (Table C3.2-6).

Table C3.2-6 Potential Flow Changes on Total Flow by the Project

Node	River	Year 7 Flow Change [a] [c] [e]		Year 15 Flow Change. Mitigated Scenario [c][d]	
		Wet Season (%)	Dry Season (%)	Wet Season (%)	Dry Season (%)
KAS1	Kasana	-20	-10	-78	-90
MOF1	Mofia	-1.3	-0.7	-5.0	-5.8
MOF2	Mofia	-0.9	-0.5	-3.6	+4.2
KAB1	Kabomboy	+3.6[f]	+12.3[f]	+3.6[e]	+12.3[e]
KAB1	Kabomboy	+1.5[g]	+4.9[g]	+1.5[f]	+4.9[f]
DIP1	Dipeta	-1.7	-1.9	-12	-16
DIP2	Dipeta	-0.8	-0.9	-5.4	-7.3
MOF3	Mofia	-0.5	-0.3	-2.1	-2.4
SOK1	Sokalwela	-9.0	-10	-80	-85
SHM1	Shimpidi	-9.0	-10	-44	-65
TSH1	Tshilongo	0[c]	0[c]	0[f]	0[f]

[a] Key question SWH-1, Section C2.11.

[b] Key question SWH-2, Section C2.11.

[c] A reduction in flow is noted by a minus (-) sign. An increase in flow is noted by a plus (+) sign. Zero percent change represents a negligible effect.

[d] Impacts do not include the effect of the proposed mining of the Goma and Fwaulu deposits.

[e] Represents high flow change scenario of 200 liters per person per day being released from the sewage treatment plant to the Kabomboy River.

[f] Represents low flow change scenario of 80 liters per person per day being released from the sewage treatment plant to the Kabomboy River.

[g] The future mining activities at Goma do not appear to be in the Tshilongo River catchment.

Wet season flows are predicted to change from +4 to -78 percent during the entire life-of-mine (Table C3.2-6). Such changes are not expected to affect amphibians as water availability is not restricted during the wet season. Mitigated

dry season flows are expected to change from +13 to -90. With augmented flows considered, effects during the dry season are therefore predicted to be negligible to low in magnitude.

Groundwater seepage with water quality that is affected by the ore stockpiles and waste rock may influence the frogs' aquatic stages (eggs and tadpoles in the Shimpidi River). No Red-listed frog species are expected to occur in the parts of the Shimpidi system being affected by water quality changes. Impacts on aquatic biota are described in Section C3.3. Results of the water quality assessment (Section C2.12) predicted that water quality effects would be negligible to low due to changes in groundwater quality and low due to sedimentation.

In addition, changes in groundwater levels due to drawdown at the mine will indirectly affect up to 12 hectares of gallery forest habitat in the Kasana and Shimpidi drainages.

Impact Analysis

Residual impacts are determined for the project's effects in all phases of the project are combined, including the construction, operation and closure phases. The impacts are summarized in Table C3.2-7.

Table C3.2-7 Residual Impact Classification for Key Question FA-1

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FA-1: What effect will the project have on fauna habitat?						
Habitat loss due to site clearing						
negative	moderate	local	long term	reversible	medium	moderate
Fragmentation and edge effects						
negative	moderate	local	long term	reversible	medium	moderate
Sensory disturbance						
negative	low	local	medium term	reversible	high	low
Changes in water flows and water quality						
negative	negligible to low	local	medium term	reversible	medium	negligible to low
Vegetation changed by dusting						
negative	negligible	local	medium term	reversible	high	negligible

Direct losses to habitats as a result of the construction and operation of the mine and related project components will amount to 2,374 hectares (16 percent of the LSA). The habitat that will be disturbed the most, relative to total area in the

LSA, is the copper-cobalt rock outcrop type (five hectares or 47 percent) followed by the copper-cobalt steppe-savannah (185 hectares or 37 percent). A total of 519 hectares of miombo woodland and 364 hectares of degraded miombo woodland will be lost as a result of the project (16 percent and 31 percent of the habitats, respectively). A total of 1,294 hectares of the agricultural mosaic will be lost (14 percent). One hectare of gallery forest will also be lost from direct impacts (three percent), with areas up to 12 hectares potentially affected by indirect effects (lowering of ground water table). One hectare of wetland will be lost (four percent). This wetland is isolated and relatively degraded around its perimeter from agricultural use. Its major significance is as a source of water and location of dry-season agriculture for local residents, and the effects on these values are addressed in the socio-economic section (C4.1).

The direction of the habitat loss due to site clearing is negative since large tracts of natural habitat will be removed or covered to form stockpiles, or tailings. The magnitude will be moderate; although larger parts of the habitats in the LSA are disturbed initially, many will be reclaimed in the long term. The geographic extent of direct clearing activity will be local. The structures will remain there for the entire life of the mining operation, and some changes will remain in place beyond that time, so the duration will be long term. The effects will, at least in part, be reversible. Due to the fact that the disturbances will occur regularly as the mines are developed, the frequency is medium. The environmental consequence is moderate.

The direction of fragmentation and edge effects is negative since edge effects and fragmentation will increase due to the project. Indirect impacts are also expected due to migration into the RSA by job-seekers and their families. The degree of fragmentation varies by habitat types as described in Section C3.4. In general a moderate impact magnitude is predicted due to the reduced size of the average habitat fragments and increased ratio of edge-to-habitat area (generally between 10 percent and 20 percent per habitat type). Most direct and indirect impacts will occur in the LSA, making them local in geographic extent. The impact duration is long term as it is likely that some fragmentation effects will persist into the closure phase. The effects are reversible. Due to the fact that human migration into the LSA may continue throughout the life of the project, the frequency is medium. The environmental consequence is moderate.

The direction of sensory disturbance is negative since it is expected that blasting will disturb breeding birds and lights attract large numbers of insects. This will alter the natural relationship between predators (bats) and prey (insects) in the area. The magnitude will be low due to the localized effect and limited number of species directly affected (less than 10 percent of the LSA outside of the project's footprint will be impacted by noise). The geographic extent will be local. The

effects of blasting and lights will remain for the life of the mining operation, thus the impact is medium term in duration and is reversible. Due to the fact that sensory disturbance may continue throughout the life of the operation, the frequency is high. The environmental consequence is low.

The direction of changes in water flows is negative but the impact is negligible to low. This is because the loss in baseflows in the three drainage lines affected by the project (the Kasana, Sokalwela and Shimpidi rivers) will be reinstated by TFM. The direction of changes in water quality is negative since sedimentation in rivers and poor water quality could influence certain frog species. The magnitude will be low due to the localized effect and because universally accepted best-management practices (BMPs) such as silt traps will be used during construction and operation of the project. The geographic extent will be local. The effects of sedimentation and pollution will remain for the life of the mining operation, thus the duration is medium term. Due to the fact that impacts will cease at closure, the effects are reversible. Due to the fact that the practices may continue throughout the life of the operation, the frequency is medium. The relatively small area that will be influenced makes the environmental consequence low. Impacts to gallery forests due to the lowering of water tables will be fully compensated for through restoration of gallery forests in other areas.

The direction of change in vegetation changes by dusting is negative since dusting could have some impact on key faunal habitats. The magnitude will be negligible due to the localized effect associated with dusting and the mitigation that will be undertaken. The geographic extent will be local, limited to the roads and other areas immediately surrounding cleared areas. The effect of dusting will remain for the life of the mining operation, so the duration is medium term. The impact will be reversible. Due to the fact that the practices may continue throughout the life of the operation, the frequency is high. The relatively small effect that the process will have on the environment makes the environmental consequence negligible.

Prediction Confidence

The direct impacts of clearing in the footprint of the project are well understood (Section C3.1). The effects of fragmentation are also well understood (Section C3.4). The prediction confidence for the assessment for alteration and fragmentation of habitats is medium. However, indirect impacts on habitat have not been quantitatively defined. The potential to reclaim specific habitats as a mitigation measure for both the loss and fragmentation of habitats is not certain.

A noise model has been used to estimate noise levels caused by the project. The effects of light generated by the project are understood with reasonable certainty.

There is some uncertainty associated with the reactions of specific species to these sensory disturbances. The prediction confidence for the assessment for sensory disturbance is medium.

Impacts on water quantity and quality have been determined with a high level of certainty (Sections C2.11 and C2.12). While the reaction of amphibians to this influence is not certain, the degree of confidence in TFM's ability to maintain appropriate water quality standards is high. The prediction confidence for the assessment for impacts on water quantity and quality is moderate.

The impact assessment for dust has considered the potential area affected in a fairly conservative manner (Section C3.1). In general, the potential impact of dust is understood. The prediction confidence for the assessment of the effects of dust is medium.

Monitoring

Monitoring programs will be implemented to ensure the adequate functioning of the habitats supporting fauna, as well as key fauna species themselves (Section D3.1.13). These programs will include:

- Inspect the off-site conservation areas regularly to ensure long-term successful habitat function.
- Monitor the effectiveness of ongoing reclamation to ensure that vegetation cover is maintained and that the desired habitat is being restored. Document the amount of habitat reclaimed each year.
- Assess the extent to which desired species in the reclaimed habitats are returning to the area.

C3.2.3.5 Key Question FA-2

Key question FA-2 is: What effect will the project have on fauna dispersion and movement?

Linkage Evaluation

Figure C3.2-1 shows the linkage between project activities and potential effects. The linkages associated with key question FA-2 are described in this section.

Barriers to Movement

The improved mine access roads (combined industrial and residential traffic) will be around of 20 meters wide. A new mine haul traffic and mine access roads of around 30 meters wide will be constructed.

A new and improved road network that is user-friendly to the local communities will increase use by humans and even encourage the settlement of new people to the area though other TFM program elements are designed to encourage immigration to the margins rather than the interior of the concession area. Any residual in-migration to the LSA will amplify the adverse effects of corridors and fragmentation.

Fugitive dust from mine traffic, ore stockpiles, waste rock and tailings storage facilities, combustion, processing and mine fleet exhaust emissions will create a sensory barrier in the area surrounding roads and the mining infrastructure.

Most mine facilities will be fenced including workshops in a common area with processing facility. The TFM camp is currently fenced and the construction village, limestone quarry and airstrip will be individually fenced.

Due to above-mentioned circumstances, this linkage is considered to be valid.

Sensory Disturbance

Continuous noise and vibration (airborne and ground) around the mining infrastructure and along roads will create a sensory barrier. However, as shown in many areas surrounding human activities, animals adapt to these low-level disturbances and no significant impact is expected. This linkage is considered invalid and is not assessed further.

Assessment Methods

Effects due to barriers to movement were evaluated qualitatively using an understanding of the types of effects typically occurring on different fauna due to development features such as roads, fences and other cleared areas.

Mitigation

Mitigation will include (Section D3.1.13):

- The mine plan incorporates buffers of viable habitat on all sides which will facilitate the movement of species around the disturbances.

- Watering roads, controlling speed limits and limiting night driving will help to minimize the impact posed by roads to the movement routes of local terrestrial animals. The effect of vehicle traffic as a barrier will be further mitigated as described under key question FA-3.
- The use of native or regionally established species will be maximized during progressive revegetation of land during operation to reduce the total size of the area impacted, and to partially restore any fauna movement corridors affected by the project.
- Prompt reclamation of powerline corridors, road rights-of-ways and other disturbed areas.
- Any areas under the control of TFM (e.g., within the fence lines) which are not intensively impacted by the project will be protected from unnecessary disturbance from TFM-related activities for the lifetime of the mine.

Results

Barriers to movement being constructed by the project include roads, fenced facilities and large tracts of disturbance at the mine site. Roads will deter animals from crossing during peak use hours. However, very little natural ground-animal movement is expected during these daylight peak hours and birds will cross these barriers by flying over roads. During the night-time, when most of the movement of local fauna is anticipated, the disturbance factor will be lower so the roads will pose less of an obstacle. It is concluded that roads do not pose a significant barrier to local fauna.

Fenced areas will pose barriers for species moving along the ground, and would generally be expected to be most problematic for movement of large animals which must migrate over large distances. Baseline field investigations show that there are very few larger mammals present in the area. Smaller animals will move through or over fences.

Impact Analysis

The impact of project disturbances and structures as barriers to wildlife movement are predicted to be negative and low in magnitude. The geographic extent will be limited to the LSA and will be local. The effect of roads as barriers will remain for the life of the mining operation, and also after the operation if the roads are left in place for the future use of local communities. As a result, the duration is long term. The option exists to remove the roads and all other barriers, however, so the impact is reversible. The potential for project developments to act as barriers for specific species will exist continuously (e.g., traffic will

continue throughout the life of the operation), so the frequency is high. The environmental consequence is low (Table C3.2-8).

Table C3.2-8 Residual Impact Classification for Key Question FA-2

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FA-2: What effect will the project have on fauna dispersion and movement?						
negative	low	local	long term	reversible	high	low

Prediction Confidence

The prediction confidence is moderate to high, recognizing the current situation regarding the fauna in the area and the existing knowledge concerning the effect of barriers on fauna. An area of low confidence is the magnitude of future indirect effects due to the migration of people moving into the area.

Monitoring

No monitoring is proposed specifically for barriers to movement.

C3.2.3.6 Key Question FA-3

Key question FA-3 is: What effect will the project have on fauna demography?

Linkage Evaluation

Figure C3.2-1 shows the linkage between project activities and potential effects. The linkages associated with key question FA-3 are described in this section.

Direct Mortality from Site Clearing

Removing potential aspects of habitat (rocks and stones) and destroying habitat (live vegetation and logs), or covering viable habitats with tailings, overburden materials, low-grade ore, gravel or buildings may lead to the direct mortality (death) of slow-moving or subsurface fauna. These groups will include slow-moving reptiles, burrowing mammals and frogs. Larger and more mobile fauna will abandon the area or only visit it occasionally.

This linkage regarding direct mortality from site clearing is considered valid.

Removal of Nuisance Fauna

A lack of the species that have the potential to become nuisance fauna (generally, small or large mammal species) was observed in the RSA during the field studies. This is, perhaps, due to the existing use, for food, of small and large mammal species by the local populations. Due to the near absence of these species, this linkage is considered invalid.

Interaction of Wildlife with Infrastructure

There is a concern that fauna might be influenced adversely due to interactions with the project, including the mine, the tailings storage facility, water ponds, infrastructure like power poles, and hazardous materials. This linkage is valid.

Increased Vehicle-Wildlife Collisions

An increase in traffic flows and any increases in speed and night driving associated with the project will result in an increase in wild animal mortalities.

Although initial mining, construction and operation activities will probably be conducted for only eight hours per day, they will shift to 24 hours per day, seven days per week during the operation of the project. This linkage is considered valid.

Increased Hunting/Collecting

It is predicted that the possibility of job opportunities will attract migrants into the concession area and region. Improved access created for the project will also enable local people to access previously remote areas more easily. This is likely to result in further habitat loss or increased harvesting of bush meat (meat from wild fauna) and animal skins for trade or consumption. This linkage is therefore considered to be valid.

Assessment Methods

Direct Mortality from Site Clearing

The quality of habitats and micro-habitats for fauna was established during the baseline study (B3.2.5.2). The assessment of impact was made by comparing the proposed level of site clearing at each area with the habitat availability and the associated fauna that would be impacted.

Interaction of Wildlife with Infrastructure

The potential effects of having wildlife interact directly with facilities on the project site such as mine structures, power poles and ponds was evaluated

qualitatively based on the types of wildlife present and experience with the effects of such infrastructure in other situations.

Increased Vehicle-Wildlife Collisions

Baseline statistics for vehicle-wildlife collisions are not available. It is expected that some groups of animals will be influenced adversely. Baseline and projected traffic levels are provided in Section C2.13. Professional judgment was used to assess the likelihood of vehicle collisions with the different faunal groups documented in the RSA.

Increased Hunting/Collecting

The potential effects of increased population pressure in the RSA on hunting and collection of (snaring, trapping) wildlife was evaluated qualitatively, based on an extrapolation of these types of activities observed taking place under baseline conditions.

Mitigation

Direct Mortality from Site Clearing

Baseline studies have confirmed that there are no threatened or other important species which have low mobility that must be relocated from the areas to be cleared. However, the following mitigation measures will be implemented to limit impacts of site clearing (Section D3.1.13):

- The area to be cleared by the project will be limited to the smallest practical footprint.
- Avoid the covering of rocky outcrop habitats by foreign materials.

Interaction of Wildlife with Infrastructure

Electrocution can occur when a bird completes a circuit between two wires or conductors. Avian-safe structures provide adequate clearances to accommodate a large bird between energized and/or grounded parts. Sixty inches of horizontal separation and 48 inches of horizontal separation are used as the standards for rupture protection (APLIC and USFWS 2005). In accordance with accepted best practice procedures (APLIC and USFWS 2005), the project will:

- Provide 60 inch minimum horizontal separation between energized conductors and/or energized conductors and grounded hardware (more distance if feasible to account for the possibility of larger birds).
- Insulate hardware or conductors against simultaneous contact if adequate sparing is not possible.

Increased Vehicle Wildlife Collisions

Staff and other road users in the RSA will be encouraged to comply with appropriate speed limits. Non-compliance by TFM staff will be penalized. Traveling at night will be discouraged as feasible. Mandatory safe-driving training programs for drivers hired by the project will be established.

Increased Hunting/Collecting

The problem of an influx of people (increased population pressure) will be addressed as a local community development issue of high priority. Very little can be done to persuade local communities to stop hunting or collecting game by snaring and trapping. However, employees and subcontractors of TFM will not be permitted to hunt or trap species on the project sites, nor to keep wildlife as pets. Non-compliance will be penalized.

Results

Direct Mortality from Site Clearing

The copper-cobalt rock outcrop habitat will be influenced the most due to the fact that most of the hills will be mined. Micro-habitats were counted in the form of units, where one unit represents a single piece of emergent bedrock, a single pile of loose stones, a single termite mound or a single tree. The important micro-habitats within this area consist mainly of bedrock (118 units per kilometer), loose stones (22 units per kilometer) and termitaria (13 units per kilometer). Some portions of the copper-cobalt rock outcrop habitat will be lost while others will be translocated as a result of the open pit mining (details on Section C3.1). Of the 93 fauna species that are expected in this habitat, no Red-listed animals were found or expected. All of these species occur in other habitats, so none of these species are restricted to this rather rare habitat (Table B3.2-5).

The stockpiles will influence a portion of the copper-cobalt mid-slope and miombo woodland foot-slope habitats. The important micro-habitats within the copper-cobalt mid-slope consist of bedrock (73 units per kilometer), stones (22 units per kilometer), dead trees with flaking bark (12 units per kilometer) and living trees (12 units per kilometer). The miombo woodland foot-slope biotopes contain living trees (108 units per kilometer), dead standing trees with flaking bark (37 units per kilometer) and dead prostrate trees with flaking bark (33 units per kilometer).

The waste rock and tailings storage facilities are positioned on the miombo woodland corridors in developed areas and human-impacted areas of the valley bottom. Their micro-habitats consist of the following:

- Corridors in developed areas:
  - Live trees (90 units per kilometer).
  - Dead standing trees with flaking bark (28 units per kilometer).
  - Dead prostrate trees with flaking bark (38 units per kilometer).
- Human-impacted areas:
  - Mostly homogenous crops (crops of one plant type) and settlements.

Most of the other development where large-scale site clearing is planned will also take place in habitats already influenced by local communities (corridors in developed areas and human-impacted areas). It is probable that the demography of the fauna in the area will not be influenced significantly. The area that will be severely impacted is relatively limited in the LSA. If the sites are gradually covered or filled, slow-moving and subterranean species would have a chance to move away, potentially escaping mortality.

More mobile groups such as birds and small mammals will not be affected, except during the breeding season, when their young in nests or burrows may be impacted.

The density of larger fauna in the area is low, so interactions are expected to be rare in the mining area. The powerlines do not traverse any areas where flying bird species (such as waterfowl) are likely to be significantly impacted. Bird mortality will also depend on the spacing of power conductors. As long as transmission line towers are used that place conductors at standard separation distances, there should be minimal risk of electrocution, for large birds that use the towers for perching. The use of mine ponds and the tailings facility for resting areas could result in same harm to birds depending on water quality.

Increased Vehicle–Wildlife Collisions

Based on the data collected to date and professional judgment, it is anticipated that a number of groups will be influenced adversely:

- Fauna active during the day:
  - Snakes and lizards – about 37 species, of which chameleons make up a large percentage of road-kills.

- Some birds – number not available; not excessive.
- Frogs – about 40 species during the rainy season.

- Fauna active during the night:
  - Owls and nightjars – blinded by lights of vehicle; 14 species.
  - Mongoose and other small mammals – 15 species.
  - Frogs – about 40 species during the rainy season.

Increased Hunting/Collecting

Local communities are using local fauna and flora extensively. Even rodents are collected as food. Numerous traps and snares have been found in the LSA. It is anticipated that an increase in people in the area (discussed in Section C4.1) will result in an increase in hunting and collecting of local fauna and flora.

Impact Analysis

The direction of the mortality due to site clearing is negative since large tracts of natural habitat will be covered to form stockpiles, dumps or tailings. The magnitude will be moderate due to the area in the LSA covered and the number of micro-habitat structures affected. Since the development will remain in the mining footprint, the geographic extent will be local. The structures will remain there for the life of the mining operation and beyond, making the duration long term. Because not all natural habitats can be reclaimed, the impact will be partly irreversible. Due to the fact that the clearing happens only once, the frequency is low. The environmental consequence is expected to be moderate (Table C3.2-9).

Table C3.2-9 Residual Impact Classification for Key Question FA-3

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FA-3: What effect will the project have on fauna demography?						
Direct mortality from site clearing						
negative	moderate	local	long term	irreversible	low	moderate
Interaction of wildlife with infrastructure						
negative	negligible	local	medium term	reversible	low	negligible
Increased vehicle-wildlife collisions						
negative	low	regional	medium term	irreversible	high	moderate
Increased hunting/collecting						
negative	moderate	regional	long term	irreversible	high	high

The direction of interaction with infrastructure will generally be negative, although there are also chances of positive impacts such as providing good resting sites. The magnitude of the negative effect will be negligible because few animals should be affected, and mitigation will be implemented if many negative effects are observed. The geographic extent will be local, the effect will be medium-term due to decommissioning of facilities at closure, the impact will be reversible and the frequency is expected to be low. The environmental consequence is negligible (Table C3.2-9).

The direction of the mortality due to increased vehicle-wildlife collisions is negative since animals may be killed. The magnitude will be low since the numbers killed are not anticipated to be large. Since the roads extend all over and beyond the mining area, the geographic extent will be regional. The vehicle-wildlife collisions will continue for the life of the mining operation so the duration is medium term. Although traffic levels will decline after operations, due to the permanency of the roads the impact is irreversible. Due to the continuous nature of the traffic, the frequency is high. The environmental consequence is moderate (Table C3.2-9).

The direction of the hunting/collecting is negative since this activity is known to have a detrimental effect on local wildlife populations based on observations in baseline studies. The magnitude will be moderate due to the large number of people who may move into the area, who will have an impact combined with those already living in the area. The geographic extent will be regional since harvesting activities may extend outside the LSA. The migrants will probably be permanent, thus the duration is long term. The impact will be irreversible unless alternate sources of protein become more available. Due to the fact that hunting and snaring continues daily, the frequency is high. The environmental consequence is predicted to be high (Table C3.2-9).

Prediction Confidence

Direct Mortality from Site Clearing

Vegetation will be cleared from the project's features such as stockpiles, the tailings storage facility and other infrastructure. The location of these areas is known (see Section C3.1). Fauna associated with these areas will either be lost or moved away. The level of confidence of the prediction is high.

Increased Vehicle Wildlife Collisions

While there is a lack of data regarding vehicle-wildlife collisions, there is a good expert knowledge base about the probability of collisions. The prediction confidence is moderate.

Increased Hunting/Collecting

While there is a lack of data regarding increased hunting/collecting and numbers of migrant workers, there is good expert knowledge base about the effects. There is also reasonable certainty about the probability of increasing populations in the area as a result of migration into the area. The prediction confidence is moderate.

Monitoring

Direct Mortality from Site Clearing

Very little monitoring of animal deaths caused by site clearing can be done during construction and operation periods.

Interaction of Wildlife with Infrastructure

Use of project ponds and power poles by bird species and other fauna will be monitored by periodic inspections. Any mortality that is observed will be recorded. Implement any required deterrence mechanisms.

Increased Vehicle Wildlife Collisions

Roads near any documented sensitive areas will be periodically surveyed to determine if fauna is being harmed as they cross these roads. Depending on the results of this monitoring, further migration measures will be considered.

C3.2.3.7 Key Question FA-4

Key question FA-4 is: What influence will the project have on species extinction?

Linkage Evaluation

Figure C3.2-1 shows the linkage between project activities and potential effects. The linkages associated with key question FA-4 are described in this section.

Possible Species Extinction

The main factors that could affect the occurrence of faunal assemblages in the area are:

- Clearing of vegetation and covering of viable habitats in the localized area of mining development.
- The possible influx and settling of migrant workers to the area.

Since the main area of mining activities and operations are restricted to a limited area, and there are no threatened species affected that are dependent on copper-cobalt habitat, the mining operation is highly unlikely to cause a threat of extinction (or local extirpation [removal of a species from an area]) to any fauna in the area. The linkage is invalid.

Should migrants settle in the RSA in large numbers, the use of natural resources is likely to increase significantly. Even if social development programs initiated by TFM are successful and assist in integrating migrants into the local area without major additional habitat loss, the issues surrounding hunting and collecting will be difficult to control and pressure on wildlife species will increase in proportion to the numbers of additional people in the area. Nevertheless, while faunal occurrence is likely to be reduced, there is no significant risk of extinction of any existing species as a result of hunting or other activities. This linkage is invalid.

Possible species extinction is not considered further in this assessment as the linkages are invalid.

C3.2.3.8 Key Question FA-5

Key question FA-5 is: How can the project have a positive effect on the habitats and associated fauna of the area?

Linkage Analysis

Figure C3.2-1 shows the linkage between project activities and potential effects. Valid linkages exist for potential long term benefits to fauna in the RSA.

Assessment Methods

This assessment is carried out using professional judgment concerning the potential benefits of sustainable project mitigation measures, based on past experience with these techniques.

Mitigation and Additional Measures

The RSA contains a variety of habitats for fauna, some of which are globally very rare, and others of which are more common but are still important in terms of biodiversity (Section C3.4). The first key to long term sustainability of fauna is the conservation of habitat. There are also social benefits associated with habitat conservation. Efforts for habitat conservation, as described in Section C3.1, are:

- Creation of three off-site copper-cobalt habitat conservation areas (Section C3.1).
- Identification of plant micro-reserves (PMR) in areas not currently planned to be disturbed by the project, or not to be disturbed in the short-term.
- Reclamation of copper-cobalt sites following recommendations in the flora action plan (Section D3.12) during operations and after closure of the project.

The second key aspect to the sustainability of fauna relates to local people understanding the value of biodiversity. Interactive education, research and conservation programs in the RSA that include local people, local schools, and the University of Lubumbashi (among others) are described in Sections C3.1 and C3.4. In training and education programs it will be necessary to emphasize the importance of the ecological integrity of the area as a basis for sustaining faunal populations in the long term. Awareness of ecological issues may assist local communities to better manage natural resources in a sustainable way.

Impact Analysis

The sustainability consequence of conservation areas and awareness programs are assessed separately, although they are both critical components for the long term sustainability of fauna. Conservation areas are of moderate importance in terms of magnitude; although they will protect key habitats, many of these habitats are not rich in fauna at the present time. A few people will be affected, the improvement will occur over the long term, and the probability of success of these areas is medium. The sustainability consequence is low. Awareness courses, such as those in schools in local areas, will potentially have a high effect. These will reach most or all of the community and will produce a long term knowledge base on fauna and other biodiversity. The probability of success of this environmental education program is predicted to be medium, with a medium overall sustainability consequence (Table C3.2-10).

Table C3.2-10 Sustainability Assessment for Fauna

Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key question FA-5: How can the project have a positive effect on the habitats and associated fauna of the area?				
Conservation area				
moderate	a few people	long term	medium	low
Environmental awareness education				
high	entire community	long term	medium	moderate

Prediction Confidence

The prediction confidence for any one mitigation measure (effectiveness of conservation areas or a particular education program) is low, as the success of each measure will depend on many factors outside of the project's control. However, if implemented in combination with several conservation areas and different kinds of education and research programs, the prediction confidence will increase to moderate.

Monitoring

Monitoring of proposed conservation areas and micro-reserves will occur as described in Section C3.1.

C3.2.4 Cumulative Effects Assessment

Key question $FA_{(ce)}$-1 relates to the cumulative effects on fauna due to the TFM project and future planned expansions of this project, in addition to effects already occurring on fauna due to impacts of local residents.

Linkage Evaluation

Should the project be expanded from production of 115,000 tonnes of copper per year to 400,000 tonnes per year, the physical extent of impacts would increase, and population levels will likely increase to support an enlarged workforce. As a result, additive effects on fauna will occur. This linkage is valid.

Assessment Methods

Detailed plans for the additional development of the project to expand to 400,000 tonnes per year are not yet available. However, such a development would include additional mines within the Fungurume ore body and an additional processing plant and tailings storage facility (Section A4.17). These effects were reviewed in the context of known baseline conditions for biodiversity. A

preliminary model for the footprint of the cumulative case project was overlaid on the mapped habitats based on the vegetation classification system (Section B3.1) in the RSA. Professional experience in relation to the changes in fauna caused by mining, plant sites, waste rock facilities, quarries, linear developments and an increased local population was used to develop an understanding of the potential effect of an expanded project. Principles developed for closure plans and other project goals for long term mitigation of effects were used to develop an assessment of long term impacts.

Mitigation

The mitigation presented above for key questions FA-1 through FA-4 will be implemented on a larger scale to address the effects of an expanded 400,000 tonnes per year project. At the time of the decision to expand the project, an additional assessment of fauna would be completed to determine if additional supplementary mitigation is needed.

Results

The effects on natural habitats and biodiversity with a larger, 400,000 tonnes per year project would be greater in magnitude than those predicted for key questions FA-1 through F-4. The types of impacts expected would be very similar to the currently planned project. Additional losses to all habitat types during project operations would be expected, including additional impacts on rare copper-cobalt habitats. Permanent effects would occur due to the development of new tailings storage areas, which will be difficult to reclaim to native habitats. In terms of percentage, the expected habitat losses for the copper-cobalt rock outcrop (47 percent) and copper-cobalt steppe-savannah (39 percent) are expected to be most important (Table 3.2-11),though no faunal species were documented as occurring exclusively within these two habitat types. Other habitats such as miombo woodland (five percent) support higher faunal diversity and will also see an increased impact under the cumulative case.

It is also important to consider that the project will be implemented in an environment that is already impacted, and the effect of the project will combine with pre-existing impacts. For example, local people already use wildlife extensively and are known to hunt and trap large numbers of individuals for food. An increase in the population of the RSA will add to this effect. The existing environment is already disturbed by agriculture and other human land use practices, which fragment habitats such as miombo woodland and gallery forest. The project will contribute to this habitat disturbance during construction and operation and, if migrants are attracted to the area as a result of the project, its influence is likely to be permanent.

Table C3.2-11 Areas Lost Due to Expanded Footprint (Includes Current Project and Expansion)

Habitat Type	Regional Study Area (hectares)	Cumulative Effects Assessment (hectares)	Land Cover Loss (percent)
agricultural mosaic	29,318	1,644	6
copper-cobalt rock outcrop	11	5	47
copper-cobalt steppe-savannah	598	231	39
disturbance	596	22	4
gallery forest	118	1	1
miombo woodland	14,794	738	5
miombo woodland degraded	2,890	444	14
old fallow field	994	0	0
wetland	147	1	1
Total	**49,466**	**3,086**	**3.8**

Impact Analysis

The direction of the effect the expanded project will have on the fauna in the area will be negative since a larger area will be influenced in a similar way as the first phase (Table C3.2-12). More infrastructure will be created, more activities will take place, and it is expected that more job-seekers and their families will migrate into the area. The magnitude will be high based on the percentages of habitats being affected (up to 47 percent of key habitats at the level of the RSA) and potentially large numbers of migrants moving into the area (with a likely population increase of over 20 percent). The geographic extent will be regional since both population and footprint effects may extend outside the existing LSA. The duration is long term since most of the impacts will last for the entire lifetime of the mine and some will remain after closure. Most of the impacts will be reversible. The frequency is high due to the fact that the mining activities will be ongoing and the impacts will continue to affect the area during this time. The environmental consequence is high.

Table C3.2-12 Residual Cumulative Impact Classification for Fauna

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question $FA_{(ce)}$-1: What effect will the expanded project have on fauna?						
Existing developments + the TFM Project + future expansion (400,000 tonnes per year)						
negative	high	regional	long term	reversible	high	high

ce = Cumulative effects.

Prediction Confidence

Information concerning the effects of a larger, 400,000 tonnes per year project is limited but a general understanding of the effects of such a project is in place and the assessment results presented in Table C3.2-13 are conservative. The prediction confidence for this assessment is moderate. If the larger project goes ahead, a new environmental assessment with more detailed information will be prepared.

Table C3.2-13 Residual Impact Classification for Fauna

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FA-1: What effect will the project have on fauna habitat?						
Habitat loss due to site clearing						
negative	moderate	local	long term	irreversible	medium	moderate
Fragmentation and edge effects						
negative	moderate	local	long term	reversible	medium	moderate
Sensory disturbance						
negative	low	local	medium term	reversible	high	low
Changes in water flows						
negative	low	local	medium term	reversible	medium	low
Vegetation changed by dusting						
neutral	negligible	local	medium term	reversible	high	negligible
Key question FA-2: What effect will the project have on fauna dispersion and movement?						
Barriers to movement						
negative	low	local	long term	reversible	high	low
Key question FA-3: What effect will the project have on fauna demography?						
Direct mortality from site clearing						
negative	moderate	local	long term	irreversible	low	moderate
Interaction of wildlife with infrastructure						
negative	negligible	local	medium term	reversible	low	negligible
Increased vehicle-wildlife collisions						
negative	low	regional	medium term	irreversible	high	moderate
Increased hunting/collecting						
negative	moderate	regional	long term	reversible	high	high

Monitoring

Monitoring efforts under the cumulative case will be similar to that proposed for the key question above, but larger in scale. If this larger project goes ahead, a

new environmental assessment with more detailed monitoring information will be prepared.

C3.2.5 Conclusions

The residual negative impacts of the TFM project on fauna are summarized in Table C3.2-13. The residual impacts on wildlife habitat include moderate environmental consequence impacts for habitat loss and site clearing and fragmentation. Low environmental consequences for fauna are expected due to sensory disturbance and changes to water quality and quantity.

A low environmental consequence for fauna dispersion and movement is anticipated due to the effect of barriers to movement such as roads.

Moderate environmental consequences for demography from demographic influences are expected due to site clearing and vehicle-wildlife collisions, while high environmental consequences are predicted as a consequence of increased hunting and collecting of fauna by local people.

The TFM project is not expected to cause extinction of any faunal component in the area, so key question FA-4 does not have any impacts associated with it.

Measures that will be used to establish long-term benefits to fauna, promoting sustainable development, include the establishment of flora conservation areas (Section C3.1) and efforts to help research biodiversity issues and help inform local people about the importance of the fauna in the RSA. Conservation areas are of moderate importance in terms of magnitude; although they will protect key habitats, many of these habitats are not rich in fauna at the present time. The sustainability consequence of this measure is predicted to be low (Table C3.2 14). Awareness courses, such as those in schools in local areas, will reach most or all of the community and will produce a long term knowledge base on fauna and other biodiversity. The sustainable consequence of this measure is predicted to be medium.

The cumulative effects of a larger mining project (the expanded project) will be negative since a larger area will be influenced, more infrastructure will be created, more activities will take place, and it is expected that more job-seekers and their families will migrate into the area. Therefore, with combined impacts on wildlife habitat, dispersion and demography, a high environmental consequence is expected (Table C3.2-15).

Table C3.2-14 Summary of Sustainability Assessment for Fauna

Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key question FA-5: How can the project have a positive effect on the habitats and associated fauna of the area?				
Conservation area				
moderate	a few people	long term	medium	low
Environmental awareness education				
high	entire community	long term	medium	moderate

Table C3.2-15 Summary of Residual Cumulative Impact Classification for Fauna

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question $FA_{(ce)}$-1: What effect will the expanded project have on fauna?						
Existing developments + the TFM Project + future expansion (400,000 tonnes per year)						
negative	high	regional	long term	reversible	high	high

C3.3 FISH AND AQUATIC HABITAT

C3.3.1 INTRODUCTION

This section presents the environmental assessment for the effects of the Tenke Fungurume Mining (TFM) project on fish and aquatic habitat. The information presented meets the requirements of the project's terms of reference (Appendix E8). This section specifically addresses fish communities, aquatic macro-invertebrates and habitat and includes details on:

- Project activities during mine construction, operation and closure that may affect fish and aquatic habitat.
- Issues and concerns identified by stakeholders and regulators.
- The impact assessment for potential impacts of the project on fish and aquatic habitat.
- Proposed mitigation measures and monitoring recommendations incorporated in the TFM project.
- The sustainability assessment related to fish and aquatic habitat in the project area.

This section is organized as follows:

- Section C3.3-2 describes the study areas.
- Section C3.3-3 discusses the approaches and results for the impact and sustainability assessments.
- Section C3.3-4 provides the cumulative effects assessment.
- Section C3.3-5 provides the conclusions of the assessment.

Detailed baseline information for this assessment is presented in Section B3.3.

A glossary of terms and acronyms used in this section is provided at the back of this volume.

C3.3.2 STUDY AREAS

The study areas for fish and aquatic habitat include the catchments draining the ore bodies and area of the TFM project footprint, and the proposed transportation corridor. The mine site is located in the upper Dipeta, Shimpidi, Sokalwela and Kasana river catchments. Construction and operation of access roads could potentially affect several catchments in the Mofia and Dipeta river catchments.

The limestone quarry and construction camp/permanent village will be in the Kabomboy catchment.

The Regional Study Area (RSA) includes proposed and potential future mining activities in the TFM project concession area. The RSA covers the Mofia and the Dipeta river catchments and a portion of the Tshilongo River catchment (Figure C1.5-1). The Local Study Area (LSA) comprises the footprint of the project and its associated infrastructure which potentially may directly impact local area catchments containing fish and fish habitat.

C3.3.3 IMPACT ASSESSMENT

C3.3.3.1 Issue Scoping

The primary potential issues identified with respect to the potential impact of the TFM project on fish and aquatic habitat are:

- Loss of fish as a result of the removal or disturbance of aquatic habitat by mine construction and operation.
- Stress to the life history and critical habitat functions of aquatic biota (fish and invertebrate communities). This stress could be a result of alterations to seasonality of stream flow (increased or decreased runoff to nearby waterbodies) due to changes in hydrologic characteristics of drainage areas, streams and wetland areas disturbed by construction and operation of the mine.
- Water quality changes during construction and operation of the mine affecting the health and survival of fish both on-site (within the project footprint) and in downstream drainages.
- Changes in fish health and residual tissue contaminants as a result of the construction and operation of the mine, production area facilities and associated infrastructure.
- The effectiveness of post-closure aquatic habitat reclamation or compensation and its contribution to sustainability.

Issues relating to fish and aquatic resources noted during the public consultation process (Section A6) include:

- The accumulation of contaminants (including heavy metals), both from the TFM project as well as cumulative effects from previous mining operations in the area.

- Potential impacts on water quality and fish habitat due to releases from the tailings dam, sediment control ponds, or releases of effluent from the processing plant.
- The interruption of groundwater and surface water flows (including spring surface flows) and their potential impacts on aquatic resources used by communities, including fishing.
- Potential impacts on surface water quality and quantity as a result of current agricultural practices and untreated wastes.

Sustainability issues related to fish and aquatic habitat include:

- Increased human population as a result of the project may increase fishing pressure on aquatic habitat quality in the LSA.

C3.3.3.2 Key Questions and Indicators

These issues and impacts have been addressed in the following analysis by a focused set of key questions as presented in Table C.3.3-1.

Table C3.3-1 Key Questions for Fish and Aquatic Habitat

Impact Assessment
FAH-1 What effect will the project have on aquatic habitat?
FAH-2 What effect will the project have on fish and aquatic biota abundance?
FAH-3 What effect will the project have on subsistence fisheries?
Sustainability Assessment
FAH-4 How can the project have a positive effect on aquatic habitat and subsistence fisheries?

Aquatic biota of significance to the proposed project includes both the fish and invertebrates that form part of the aquatic ecosystem in the project area. By association, the aquatic habitats that these organisms depend on to complete their life history are a critical part of the aquatic ecosystem.

Indicators and measurable parameters used for the assessment of fish and aquatic resources are summarized in Table C3.3-2. The level of available information from the baseline, literature or local specialists did not always allow a quantifiable assessment. As a result qualitative evaluations based on professional judgments also were used.

Table C3.3-2 Indicators and Measurable Parameters for Fish and Aquatic Habitat

GRI Indicator[a]		Measurable Parameter	ESIA Indicators	Question
EN28 EN32	water sources and ecosystems/habitat significantly affected by discharge of water and runoff water sources and related ecosystems/habitat significantly affected by use of water	- stream order - number of watercourses affected - water flow - reclamation habitat type - water quality and suspended sediment guidelines	- net loss of fish habitat - water quality and suspended sediment guidelines - qualitative assessment of long-term changes to aquatic community structure - exceedence of water quality criteria identified by the guidelines	FAH-1 what effect will the project have on aquatic habitat?
EN28	number of IUCN[b] Red List species with habitat in areas affected by operations	- species present - relative abundance and diversity - aquatic health assessments - statistics on the importance of fishing as an activity - water quality guidelines for the protection of aquatic life	- conservation status (IUCN[b] and published checklists) - water quality guidelines for the protection of aquatic life - plant operation, water intake, tailings discharge - exceedence of water quality criteria identified by the guidelines	FAH-2 what effect will the project have on fish and aquatic biota abundance?
EN28 EN32	water sources and ecosystems/habitat significantly affected by discharge of water and runoff (as they relate to fish species used in subsistence fisheries) water sources and related ecosystems/habitat significantly affected by use of water (as they relate to fish species used in subsistence fisheries)	- surface water quality and prediction - metal concentrations in baseline fish tissue - predicted fish abundance - statistics on fish harvest	- risk values from the literature - professional judgment and evaluation - changes to fish harvest	FAH-3 what effect will the project have on subsistence fisheries?

[a] Global Reporting Initiative 2005 (GRI 2005).

[b] World Conservation Union (IUCN 2001, 2006).

The conclusions of the hydrogeology, surface water hydrology (water flow) and surface water quality assessments (Sections C2.10, C2.11 and C2.12) have been considered as well as the preliminary design for the mine and support facilities (Section A4).

C3.3.3.3 Assessment Criteria

Table C3.3-3 provides the impact description criteria used to quantify changes in indicators. The screening system for sustainability consequence is provided in Section A5.

Table C3.3-3 Impact Assessment Criteria for Fish and Aquatic Habitat

Direction[a]	Magnitude[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
positive **negative** or **neutral** for the measurement endpoints	**negligible**: no measurable change **low**: slight change to existing background **moderate**: marginal (10 to 20%) change **high**: substantial (>20%) change	**local**: effect restricted to the LSA **regional**: effect extends beyond the LSA and into the RSA **beyond regional**: effect extends beyond the RSA	**short-term**: <3 years **medium-term**: 3 to 20 years **long-term**: >20 years	**reversible** or **irreversible**	**low**: occurs once or rarely **medium**: occurs intermittently **high**: occurs continuously

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

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

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

(d) Duration: length of time over which the environmental effects occurs. Considers a two-year construction period and a 20-year operations period.

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

(f) Frequency: how often the impact occurs.

C3.3.3.4 Key Question FAH-1

Key question FAH-1 is: What effect will the project have on aquatic habitat?

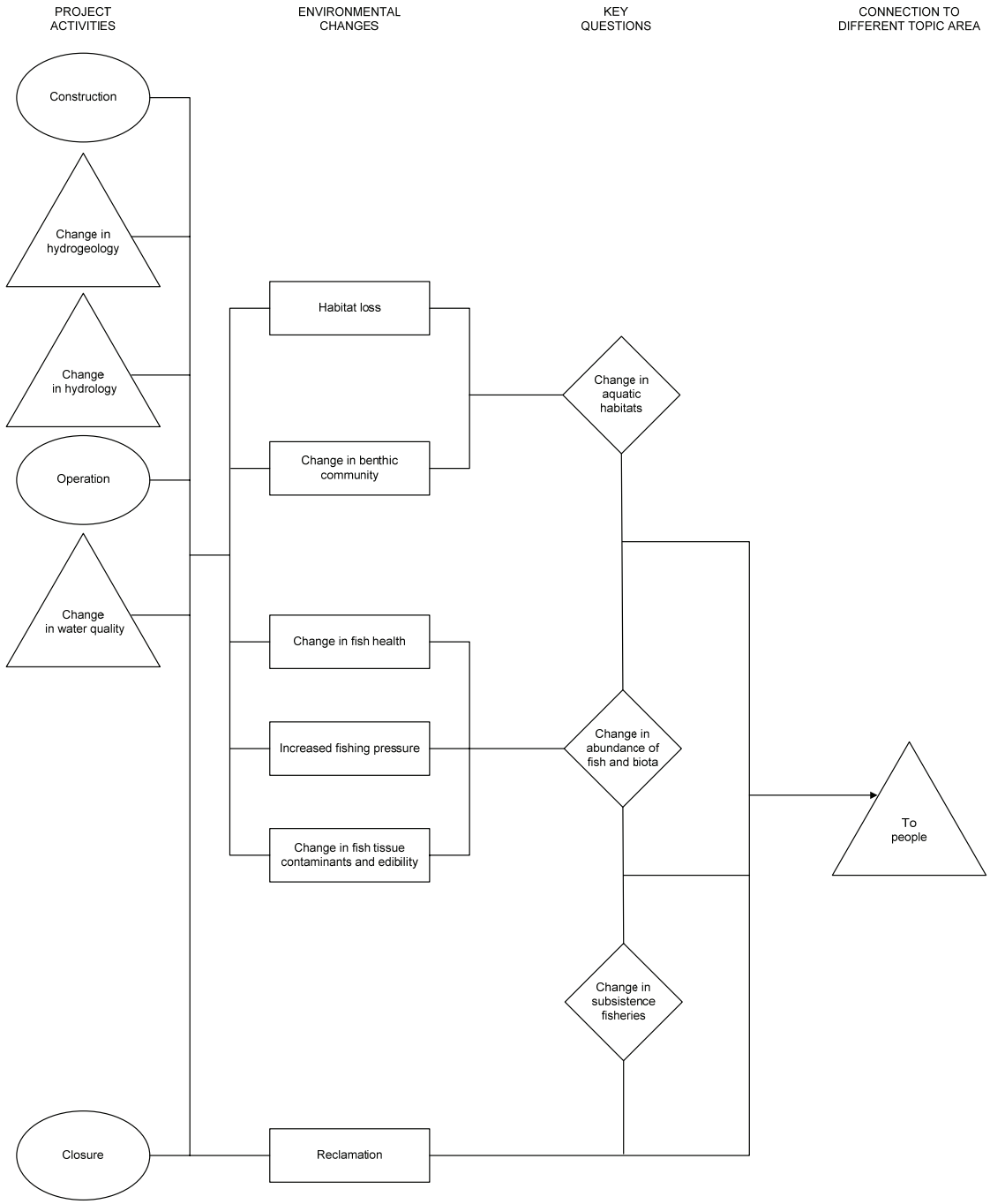
Linkage Evaluation

The linkages between project activities and potential effects are shown in Figure C3.3–1 below. Aquatic habitat can be affected by mine site activities during the construction, operation and closure phases. Habitats can also be affected by additional facilities and services such as watercourse crossings by access and haul roads.

Results from other disciplines were used in the fish and aquatic resources assessment as indicated in Figure C3.3-1: hydrogeology (Section C2.10), hydrology (Section C2.11) and water quality (Section C2.12). Key environmental changes that may affect fish and aquatic resources include:

- Habitat loss.
- Change in benthic community. Invertebrates that live on stream bottoms provide food for fish.

Figure C3.3-1 Fish and Aquatic Resources Linkage Diagram



- Change in fish health. Fish health can be affected by change in flows and quality including sedimentation.
- Increased fishing pressure, measured as an increase in the number of people who fish for subsistence purposes as compared to baseline data. Increased in-migration to the area can result in more fish being caught for consumption.
- Change in fish tissue contaminants and edibility. This can result from changes in water quality.
- Reclamation. This can have a positive effect.

These changes can lead to the key questions pertaining to change in habitat, abundance of fish and biota, and subsistence fisheries as indicated in Figure C3.3-1.

Changes in the availability, quality or quantity of fish and aquatic habitat may result from the following effects:

- Disturbance and displacement of stream channels.
- Changes in downstream water flow.
- Changes in surface water quality.

Disturbance and Displacement of Stream Channels

Removal or diversion of stream channels and wetland during mine construction will impact aquatic habitats. This may affect the capability of the local catchment to support fish and other aquatic biota. Loss and disturbance of these habitats may also occur during access road and transportation corridor construction. This linkage is considered valid.

Changes in Downstream Water Flow

Change in water flow (surface water or groundwater) will occur during mine activities as a result of the displacement of headwater streams (Kwatebala pit and other facilities) by the TFM project's footprint and by discharge from the camp sewage treatment plant to the Kabomboy River. Changes associated with groundwater supply for process water and pit dewatering (pumping of excess water from the pit) wells, were identified as having a potential negative impact on groundwater discharge to springs and subsequently surface water baseflows in the Kasana, Sokalwela and Shimpidi catchments and to a lesser extent in downstream portions of the Mofia and Dipeta rivers fed by these tributaries (hydrogeology Section C2.10 and surface water hydrology Section C2.11).

Baseflow impacts may be mitigated during mine operation by the discharge of excess pit dewatering water to augment stream flow. Flow augmentation has been proposed for the Kasana, Shimpidi and/or Sokolwela rivers after Year 7 (when the groundwater table will be intercepted by the mine pit) if monitoring indicates that reduced baseflows are an issue for key habitats such as gallery forest and associated aquatic systems. Potential changes in base and total stream flow will be reduced after mitigation. This linkage is considered valid.

Excess pit dewatering water may reach approximately 600 Liters per second at certain times of the year (Appendix C2.10-I). Release of up to 200 Liters per second of water into each of the three local rivers may occur. This could have an effect on erosion and channel morphology, and hence aquatic habitat. This linkage is considered valid.

A diversion and attenuation dam (Dipeta River) may be required for future development of the Goma pit (Surface Hydrology Section C2.11.3.1). However, surface water hydrology and groundwater impacts have not been determined as no detailed development plans are yet available. The potential impacts of the diversion on aquatic resources will be fully assessed in an ESIA prior to development of the Goma pit. Diversion of stream flow around the Goma mine pit should not affect the volume of downstream flow, unless an attenuation dam (i.e., a dam that holds back water) is required. This linkage is considered valid.

Changes in Surface Water Quality

Changes to surface water quality (i.e., sediments, contaminants) may occur as a direct result of runoff from project site construction and surface water management (including containment ponds) during operation (Section C2.12). Water quality may also be affected by wastewater releases, and spills during mine operation. Changes in water quality can directly or indirectly affect the productivity of aquatic habitat. This linkage is valid for drainages associated with, and downstream of, the mine.

Assessment Methods

Disturbance and Displacement of Stream Channels

The total length of stream channels disturbed (i.e., fragmented or flows directly altered) within the TFM project footprint was determined by geographic information system (GIS) measurement. The habitat types and the integrity of these channels were identified using baseline data (Section B2.3). Disturbance and alteration of aquatic habitat along the Mulumbu access road, Fungurume bypass, and the Kafwaya cutoff road, were assessed from map data and identification of potential watercourse crossings.

Changes in Downstream Water Flow

Changes in surface water hydrology (Section C2.11) and hydrogeology (Section C2.10) were examined for the project area. Impacts on aquatic habitats identified during the baseline survey were discussed qualitatively.

Changes in Surface Water Quality

Predicted changes in surface water quality (Section C2.12) and hydrogeology (Section C2.10) were examined for the mine area and the watercourses along the main access road. Impacts on aquatic habitats identified during the baseline survey were discussed qualitatively.

Mitigation

Mitigation measures that will moderate the impact of habitat loss or alteration as a result of clearing, removal of stream channels, diversion of stream channels and changes to water flow and quality include the following:

- The surface water action plan described in Section D3.1.5 and the mine waste action plan described in Sections D3.1.7, D3.1.8 and D3.1.9.
- Minimum flow guidelines will be developed, relative to baseflow, for the protection of aquatic biota in the Kasana, upper Mofia, Sokalwela and Shimpidi catchments. This includes instantaneous flow requirements to assist with the pit water discharge identified for groundwater/surface hydrology mitigation.
- Release of intercept dewatering water may be as high as 200 liters per second to each of the Kasana, Sokalwela and Shimpidi drainages (based on the upper range estimate of the groundwater sensitivity analysis (Appendix C2.10-I). This volume is within range of the storm flows in each of the three rivers. However, this is about double the wet season baseflows (Section B2.11). This could cause erosion and changes to aquatic habitat if there are continuous flows at this level. Monitoring of river morphology will be undertaken monthly to determine if excessive erosion is taking place (Section D3.1.12). If erosion is shown to be a problem, excess water will be piped to the Dipeta River or additional erosion mitigation will be taken.
- Implementation of watercourse crossing guidelines to minimize in-water work and to control sediment levels within specified levels for the protection of aquatic habitat and biota.
- Revegetation, as feasible, of all disturbed riparian habitats at road watercourse crossings to minimize erosion and sediment loading.
- At closure, where and if hydrologic and water quality conditions allow, establish a surface water outlet from the mine pit lake to stabilize seasonal flows in downstream reaches of the drainage.

Construction

- The quality, quantity and flow direction of surface water runoff will be established before construction and such information must guide the planning of all construction activities.
- A system of segregation of non-contact and contact stormwater runoff will be established, allowing only non-contact runoff to drain to local rivers and sediment traps maintained as described in Section D3.1.5.
- Locate stockpiles or mounds away from sensitive receptors and watercourses, taking the predominant wind direction into account.
- Water resources will be protected from the effects of spills of pollutants such as fuels, lubricants, hydraulic fluids, refuse, cement, sewage, chemicals, wash water, organic materials, etc. If a spill occurs during construction, TFM's EM manager will be notified and the affected area decontaminated properly.
- Any material removed from the in-stream or riparian habitat will be stored outside the riparian zone, to eliminate potential for runoff to the streams.
- Water for construction and drinking purposes during the construction period will be obtained from a sustainable source that will not eliminate existing water supplies to the aquatic ecosystem.
- All water discharged from the construction site must meet applicable water quality standards (Section A2.7).

Operation

- Instantaneous minimum baseflow releases will be maintained in the Kasana, Shimpidi and possibly Sokalwela rivers through intercepted pit water discharge (assuming sufficient discharge is available) as recommended in the groundwater action plan (Section D3.1.6).
- Monitor pit water quality and, if it deteriorates beyond the guidelines for discharge (see Section A2.7), it will be incorporated into the process water circuit.
- Water for operational and drinking purposes must be obtained from a sustainable groundwater source and such abstraction must not eliminate existing water supply to the aquatic ecosystem.
- A spill response plan will be developed and implemented to protect water resources from the effects of spills of pollutants such as fuels, lubricants, hydraulic fluids, refuse, cement, sewage, chemicals, wash water, organic materials, etc.
- If excess water inventory in the return water dam makes controlled discharge of the water advisable, the water will only be released if it meets the water quality standards stipulated in Section A2.7.

- Project-related activities within the concession will be controlled to limit the impact on the water quality of rivers, streams and wetlands. All works proposed by TFM or its contractors within 20 meters of water bodies must be approved by the TFM EM Manager prior to implementation and must include appropriate best management practices to minimize disturbance to the stream banks or bed, control erosion, limit vehicle operation, and minimize storage or use of hazardous fuels and chemicals.
- Include riparian habitat conservation themes in any local environmental education programs that are developed for the TFM project.
- Provide assistance to the local government for watershed planning/land use zoning (Section C3.1).

Results

Disturbance and Displacement of Aquatic Habitat

Mine Disturbance Area

The footprint of the Kwatebala mine area will displace several small headwater stream channels and a small endorheic (closed) wetland. Channels affected occur primarily within a single catchment (Kasana River). An endorheic wetland is also located in the headwater of this drainage. The potential extent of channel displacement as a result of the Kwatebala pit is summarized in Table C3.3-4. Disturbance from the Goma and Fwaulu pits have not been quantified in this assessment, but the Fwaulu mine may impact the Dipeta and, to a lesser degree, the Sokalwela catchment.

Table C3.3-4 Aquatic Habitat Displacement by Mine Development[(a)]

Type	Number	Channel Length (m)
streams 1st order	5	3,620
streams 2nd order	2	2,093
streams 3rd order or greater	2	689
endorheic wetland	1	-

(a) Within base case mine/ tailings site footprint.

- = Not applicable; wetland is approximately one hectare in size.

m = meter.

The first order headwater streams (the smallest streams, with no tributaries) make up a majority of the watercourses within the limits of the project footprint (Table C3.3-4). They can influence aquatic habitat quality downstream through flow volume and physical/chemical characteristics (i.e., water temperature,

oxygen, sediment). Most of these streams within the project footprint are non-perennial and do not contain fish habitat because of severe habitat limitations (ephemeral [water present only in the wet season] flows, high gradients, disturbance by cropping [farming/deforestation] activities). Although first order headwater stream habitats will be lost within the project footprint, the effect on the overall availability and productivity of aquatic habitat in the LSA and RSA is expected to be negligible.

Some second (formed by joining of two first order streams) and third order streams will also be displaced in the Kwatebala area. These slightly larger streams generally contain a limited amount of fish and invertebrate habitat within primarily disturbed locations due to local cropping activities. Similarly, the elimination of these streams within the project footprint will have a negligible to low impact on the availability of aquatic habitat in the catchment.

The one small, isolated wetland area that will be affected is a permanent wetland. The wetland has already been impacted by dry-season (market-garden) agricultural use, is not fish-bearing during the wet season and loss of the wetland will have negligible impact on aquatic habitat.

Transportation Routes

Additional facilities such as haul roads and access roads may potentially disturb aquatic habitat in the LSA and RSA catchments. This could take place during instream crossing construction activities and by surface runoff (i.e., sediment from erosion). Along the proposed on-site primary access roads, two first order streams will be crossed by the Mulumbu access road/Fungurume bypass and five first order streams will be crossed by the Kafwaya cutoff road. Effects on aquatic instream habitat will be temporary. These streams are located in disturbed habitats and are headwaters that are primarily non-perennial. These watercourses are unlikely to contain significant aquatic habitat. Upgrades to crossings on existing roads may similarly temporarily disturb aquatic habitats.

Effects will be mainly a short-term disturbance of riparian (land associated with banks of rivers, streams, lakes and ponds) and instream habitat and limited to the construction period, with negligible impacts. Long-term, permanent disturbance could occur depending on the type of road crossing (culvert, bridge, water ford) required. Suitable watercourse crossing guidelines will be followed to ensure the use of best management, design and environmental mitigation measures.

Changes in Downstream Water Flow

During construction of the mine, some short-term impacts on downstream flow may occur in aquatic habitats as water management infrastructure is developed.

Table C3.3-5 presents the predicted changes in total flow at eleven hydrology assessment nodes (Surface Water Hydrology, Section C2.11) prior to, and after, the initiation of dewatering that is expected to begin in 2015.

Table C3.3-5 Potential Flow Changes on Total Flow by the Project

Node	River	Year 7 Flow Change [a] [c] [e]		Year 15 Flow Change. Mitigated Scenario [c][d]	
		Wet Season (%)	Dry Season (%)	Wet Season (%)	Dry Season (%)
KAS1	Kasana	-20	-10	-78	-90
MOF1	Mofia	-1.3	-0.7	-5.0	-5.8
MOF2	Mofia	-0.9	-0.5	-3.6	+4.2
KAB1	Kabomboy	+3.6[f]	+12.3[f]	+3.6[e]	+12.3[e]
KAB1	Kabomboy	+1.5[g]	+4.9[g]	+1.5[f]	+4.9[f]
DIP1	Dipeta	-1.7	-1.9	-12	-16
DIP2	Dipeta	-0.8	-0.9	-5.4	-7.3
MOF3	Mofia	-0.5	-0.3	-2.1	-2.4
SOK1	Sokalwela	-9.0	-10	-80	-85
SHM1	Shimpidi	-9.0	-10	-44	-65
TSH1	Tshilongo	0[c]	0[c]	0[f]	0[f]

[a] Key question SWH-1, Section C2.11.

[b] Key question SWH-2, Section C2.11.

[c] A reduction in flow is noted by a minus (-) sign. An increase in flow is noted by a plus (+) sign. Zero percent change represents a negligible effect.

[d] Impacts do not include the effect of the proposed mining of the Goma and Fwaulu deposits.

[e] Represents high flow change scenario of 200 liters per person per day being released from the sewage treatment plant to the Kabomboy River.

[f] Represents low flow change scenario of 80 liters per person per day being released from the sewage treatment plant to the Kabomboy River.

[g] The future mining activities at Goma do not appear to be in the Tshilongo River catchment.

During mine operation prior to pit dewatering, the water management plan gives priority to using surface runoff as process water (water used in the processing plant), including run off from the waste rock facility, thus some catchments may experience a marked loss in flow from surface runoff. The Kasana catchment is predicted to experience a 10 percent (dry season) to 20 percent (wet season) total flow reduction at site KAS1 because of the loss of river basin area (Table C3.3-5). Other downstream catchments will experience relatively insignificant reductions, although both the Sokalwela and Shimpidi rivers will experience a 10 percent (dry season) to 9 percent (wet season) decrease.

Surface water baseflows in the local catchments (Kasana, Sokalwela and Shimpidi) are controlled by groundwater levels (springs), which will be impacted by supply and dewatering (wells used to intercept ground water from entering the pit) wells, in particular after Year 7 when the mine depth intercepts the groundwater table. Current indications (Section C2.11) are that the springs

feeding the Kasana and Sokalwela rivers will be affected to the degree that they will stop flowing as a result of mine dewatering. The springs feeding these two rivers are located relatively close to the proposed Kwatebala pit and probably within the cone of depression resulting from pit dewatering. The Shimpidi River is further from the mine and the surface hydrology assessment estimated that the spring flows to the Shimpidi River will be reduced by 75 percent (without mitigation) once mine dewatering is fully developed. It was assumed that a reduction in spring flow (caused by a reduction in water table levels) will also reduce the shallow groundwater or interflow. The potential flow reduction on the storm flow is also significant in the upper reaches of the Shimpidi River. Although smaller, there will also be reactionary downstream flow reductions in the larger rivers fed by these tributaries (e.g., the Mofia and Dipeta rivers).

Depending on the need as indicated by monitoring, excess pit dewatering water may be discharged to surface water during mine operation (after Year 7) to augment the dry season baseflow (Section 2.11., Table C2.11-10). This would partially limit the extent of instream flow impacts on aquatic habitat and biota. Decreases in downstream flows in the Kasana River, the Shimpidi River and the upper Sokalwela River will result in changes to aquatic habitat (including water depth, wetted channel area and velocity) and potentially to ecosystem function and suitability of use by resident fish, other aquatic biota and riparian vegetation that are dependent on seasonal fluctuations in flow and water levels for completion of life history functions (i.e., such as spawning by some fish species). The water quality assessment (Section C2.12) indicates that the pit dewatering water quality will meet all applicable guidelines.

Increases in flow will be experienced in the Kabomboy River, due to discharges from the camp sewage treatment facility. The predicted increased volume of flow during operation (Table C3.3-5) will slightly alter physical aquatic habitat parameters.

The modifications to the catchments by the mine will result in changes to the aquatic habitat and ecosystem components. Further downstream, impacts from mine-related flow reductions will be lower in magnitude and dependant on the distance from the source of the mitigated flow change to the point of assessment.

Change in Surface Water Quality

Clearing of the mine area, diversion of headwater streams, operation of the mine pits, construction of the plant site and additional facilities will potentially affect surface water quality in the project area during the construction period (Section C2.12). These changes, could alter riparian and instream aquatic habitat and affect the presence and abundance of aquatic biota in parts of the receiving catchments.

Water quality changes affecting aquatic habitat in the mine area will be mainly associated with instream work activities, erosion (sedimentation) during surface water runoff, spills or 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 downstream of the project footprint and along the access or service roads. Use of applicable BMPs during construction will minimize potential effects. Impacts are expected to be low.

Use of suitable design standards and mitigation during operation of the sewage treatment facility near the Kabomboy River will minimize effects on aquatic habitat.

Impact Analysis

Residual impacts of aquatic habitat loss as a result of the project construction, operation and closure are summarized in Table C3.3-6. Most effects are predicted to have low environmental consequences. Changes in downstream flow during the operation phase may have low to high consequences on aquatic habitat, depending on the location in the catchments.

Table C3.3-6 Residual Impact Classification for Effects on Aquatic Habitat

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FAH-1: What effect will the project have on aquatic habitat?							
Disturbance and displacement of aquatic habitat							
construction	negative	high	local	short to long-term	No	medium	low
operation	negative	low to moderate	local	medium-term	No	medium	low to moderate
closure	positive	low	local	long-term	n/a	low	low
Changes in downstream water flow							
construction	negative	low	local	short-term	No	medium	low
operation	negative	low to high	local	long-term	yes	medium	low to high
closure	positive	low	local to regional	long-term	n/a	low	low
Changes in surface water quality							
construction	negative	low	local	short-term	yes	medium	low
operation	negative	low	local	long-term	yes	medium	low
closure	positive	low	local	long-term	n/a	low	low

n/a = Not applicable.

Prediction Confidence

Disturbance and Displacement of Aquatic Habitat

The prediction confidence for impact ratings for habitats within the mine disturbance area is high as these sites will be impacted. The prediction

confidence for impact ratings for habitats downstream is considered low because of the limited and generally qualitative information available.

Changes in Downstream Water Flow

Impact predictions are subject to moderate to high uncertainty as a number of assumptions were used in the assessment (e.g., assumptions for groundwater contributions) and limited information on seasonal flow related changes to aquatic habitat and biota functions.

Changes in Surface Water Quality

Impact predictions for water quality are subject to moderate uncertainty as conservative assumptions were used in the assessment. These assumptions are described in Section C2.12.

Monitoring

No monitoring is proposed specifically for construction or operation effects on aquatic habitat within the mine disturbance area, other then monitoring to minimize disturbance areas. This is because these units will be totally impacted during development. Water quality will be monitored as described in Section C2.12.

Monitoring physical habitat and resource responses to flow reduction and augmentation plans is recommended for the catchments (Kasana, Sokalwela and Shimpidi) most impacted. Because of limited present background data on groundwater and surface water, and the uncertainties associated with supplemental flow prescriptions and the status of the aquatic resource, an adaptive management approach should be considered that allows revisions of the initial/interim baseflow prescription based on monitoring. To be effective, monitoring should begin several years prior to implementation of any flow augmentation (i.e., prior to Year 8).

Post-disturbance monitoring of the effectiveness and integrity of reclaimed on-site aquatic habitats or compensatory features will be implemented at closure.

C3.3.3.5 Key Question FAH-2

Key question FAH-2 is: What effect will the project have on fish and aquatic biota abundance?

Linkage Evaluation

The abundance and survival of fish and aquatic invertebrate communities can be affected by mine activities during construction, operation and closure phases (Figure C3.3-1). Changes could result from:

- Habitat modification.
- Aquatic health.
- Restoration programs.

Habitat Modification

Removal and drainage of existing watercourses and waterbodies eliminates the capability of these specific areas to support fish and other aquatic biota. It may also result in the mortality (death) of biota (fish or invertebrate communities) within the mine disturbance footprint. The alteration or disturbance of aquatic habitat in catchments downstream of the mine (change in flows and water quality) can directly or indirectly affect the productivity and composition of fish and invertebrate communities, and if not suitably mitigated also result in mortalities (i.e., if springs providing baseflows dry up or the timing and volume of mitigation baseflows is insufficient). Disturbance of fish and invertebrate populations will also occur during watercourse crossings associated with access and haul roads. Loss and disturbance of the fish and other aquatic communities will occur during the mine project.

Physical habitat assessments have been discussed in key question FAH-1. The use of these habitats by fish species and/or macro-invertebrates will be addressed for this key question.

Aquatic Health

Aquatic health effects result when the physical or chemical characteristics of water vary outside the normal tolerance range of fish or invertebrate biota. Changes in health can result from construction and or operation of mine production facilities and associated infrastructure. Aquatic health can be affected by contaminants (from spills, effluent [waste] discharges and air emissions), changes in water quality (entrained sediments) and quantity (flows) and lethal (death-causing), sub-lethal or chronic effects on fish (certain activities of construction in or near water).

Restoration Programs

If naturally functioning drainages can be developed, or are present after closure, restoration programs for local aquatic fauna and fish may be feasible.

Assessment Methods

Species taxonomy and community composition data (fish and macro-invertebrates) is described by qualitative and quantitative population sampling taken during the baseline survey within the various catchments within the mine area (Section B3.3). Habitat loss data was generated for watercourses (see key question FAH-1) and habitat integrity information was developed during the baseline site surveys. The conservation status of endemic (locally occurring) and native fish species was reviewed from recent published checklists and the World Conservation Union (IUCN) Red List (2006). Fish and ecosystem health was judged by interpretation of predicted water quality and quantity data. The mine reclamation and closure plan (Section D5) was used to evaluate recovery options and sustainability.

Mitigation

Mitigation measures to minimize the loss of fish populations and invertebrate communities from activities associated with mine construction and operation include:

Design Features

- Habitat-specific mitigation measures for water quality, as presented in Section D3.1.5, will provide some direct or indirect protection to fish communities and other aquatic biota.

Construction and Operation

- Utilize excess water created through pumping of groundwater for pit dewatering to maintain instantaneous minimum dry season baseflows in the Kasana, Sokalwela and Shimpidi rivers, to the extent that these flows exceed the water needs of the processing facility.
- Restoration of natural drainages, where feasible, so that pre-disturbance flows are established and aquatic habitat will naturally re-establish over time.

Results

Habitat Modification

Fish community sampling within the TFM project study area documented 15 fish species, of which four are currently identified by the World Conservation Union (IUCN) as having status as species of Least Concern. Species of Least Concern are defined as widespread species with no major widespread threats identified (IUCN 2006). None of these four species of Least Concern occurred within the headwater sites or catchments directly affected by the mine development.

Mine Disturbance Area

Within the area of disturbance for the Kwatebala pit (first and second order stream sites on the Kasana catchment) the fish community structure at the representative survey site was limited to low densities of a single native species (*Kneria wittei*). The stream reach in this area displayed disturbance from cropping activities, deforestation and exotic vegetation. These factors result in poor conditions for the maintenance of fish communities.

The remaining catchment (Dipeta River tributary) within the mine disturbance area (the future Goma pit area) was not sampled. The nearby Sokalwela River downstream tributary contained low numbers of two species of fish. Habitat was similarly degraded in the Sokalwela River downstream tributary by human activities such as deforestation and agriculture.

The project will impact small populations of resident native fish using the areas of mine site drainages within the disturbance boundary. Population level impacts to these species are likely negligible to low because of their low densities, high levels of existing habitat degradation and widespread distribution in the LSA. Furthermore, data from the TFM socio-economic baseline indicates that fishing and consumption of locally-captured fish do not take place at significant levels in the LSA.

Downstream Drainages

Modifications to the upper catchment within the mine area will result in changes to the resident aquatic communities. The mine footprint should have little effect on downstream surface flows except on the Kasana drainage. Water quality (i.e., sedimentation) may be affected in upper tributaries of some catchments (i.e., Shimpidi River) by runoff from the plant site and soil stockpiles. However, changes to groundwater supply could potentially affect baseflows in catchments (Kasana, Shimpidi and Sokalwela rivers) draining the mine area.

Roads

Road construction could temporarily impact resident aquatic biota (fish and invertebrate communities) during construction, resulting in displacement or mortalities (deaths). Impacts to populations of these species are likely to be short term and negligible.

Aquatic Health

Changes to aquatic health could occur primarily on a local level due to the effects of:

- Increased sediment entrainment during construction.
- Accidents and spills into waterbodies.
- Effluent (waste) and sewage discharges into waterbodies.
- Deposition of air emissions into local waterbodies.
- Seepage or infiltration from the mine area affecting groundwater quantity and quality downstream of the mine area.

Implementation of BMPs and mitigation strategies should limit impacts to low or insignificant levels.

Restoration

At closure, the realignment of drainages to approximate their predisturbance form will re-establish aquatic habitat and provide opportunities for the establishment of aquatic resources and local native fish species. 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.

Impact Analysis

Residual impacts of changes to the abundance and structure of aquatic communities are summarized in Table C3.3-7. Most effects are predicted to have a low to moderate environmental consequence except for the effects of restoration, which cannot be accurately predicted.

Prediction Confidence

The status of fish species in the mine disturbance area is moderately well understood. However, the level of information on life history for most fish species and other 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 is low because of the lack of seasonal and community life history data to define critical habitats and functions (i.e., spawning).

Table C3.3-7 Residual Impact Classification for Effects on Fish and Aquatic Biota Abundance

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FAH-2: What effect will the project have on fish and aquatic biota abundance?							
Change due to habitat modification							
construction	negative	high	local	short to long-term	no	medium	low
operation mine	negative	low	local	long-term	no	medium	low
operation downstream	negative	low to moderate	local	long-term	no	medium	moderate
Change to aquatic health							
construction	negative	low	local	short-term	yes	low	low
operation	negative	low	local	long-term	yes	low	low
Restoration							
closure	positive	low	local	long-term	yes	low	-[(a)]

[(a)] Cannot be accurately predicted.

Monitoring

The following monitoring is recommended:

- Monitor the success of baseflow augmentation, and refinement of instream baseflow requirements, on aquatic communities and habitat function in the Kasana, Sokalwela and Shimpidi rivers.

C3.3.3.6 Key Question FAH-3

Key question FAH-3 is: What effect will the project have on subsistence fisheries?

Linkage Evaluation

The harvest of fish from subsistence fisheries can be affected by mine activities during construction, operation and closure phases. Changes may result from:

- Accessibility to traditional fisheries (watercourses or waterbodies).
- Fish abundance and availability.
- Fish health and condition.

Accessibility

Changes in subsistence fisheries could occur if change in availability of access (i.e., mine area development and security) affected subsistence fishing locations. No suitable fish-bearing waters or evidence of traditional fishery locations were

present within the immediate project footprint or areas likely to be affected by transportation route changes. This linkage is considered invalid.

Fish Abundance and Availability

Mine operation will not interfere with or eliminate fish populations being currently harvested. However, changes to fish health and condition in the downstream drainages could occur due to mine effects within the LSA in the downstream drainages and infrastructure (i.e., service roads). The immigration of construction and operation workforce and families are expected to result in increased consumptive exploitation of the available fisheries resource within the region. This is a valid linkage if suitable species/populations exist in the local and regional area catchments for harvest. However socio-economic baseline surveys indicate that fishing is not an important activity either from an economic or subsistence standpoint.

Fish Health and Condition

Fish health and condition (suitability for human consumption) can be affected by contaminants (from spills, effluent [waste] discharges and air emissions), changes in water quality, and certain activities of construction in or near water that may have lethal, sublethal or chronic effects on fish..

Assessment Methods

Mine plan information was reviewed to evaluate changes related to infrastructure.

Fish harvest from subsistence fisheries was determined from comprehensive observations during the baseline survey. Fish harvest was projected by professional judgment from the species composition observed or from communications with any local fishermen encountered during the baseline survey.

Fish health was judged by interpretation of predicted water quality and quantity data. Fish condition was evaluated from baseline tissue contaminant data collected from fish in the lower Dipeta River and evaluation using United States Environmental and Protection Agency (US EPA) 2005 risk-based guideline concentrations (reported in Section B3.3.5).

Mitigation

Mitigation measures for any effects on artisanal fisheries will include:

Construction and Operation

- Mitigation measures for water quality, as presented in Section D3.1.5, will provide protection to fish communities, fish health and condition. Indirect benefits of mitigation for fish will be indirectly experienced by subsistence fishermen.

Results

The mine development plan (Section A4) indicates in-migration of workers during construction and operation. Many of these workers, as a conservative scenario, will likely bring additional family members to the concession area as well. They will directly (harvest) or indirectly (purchase) local food sources including fish. Observations during baseline surveys suggest a relatively extensive harvest of fish in the larger higher order streams of the LSA during low-flow periods (not sampled during the present study). However, insufficient information is available to accurately determine the extent and degree of the artisanal fisheries in the area. Socio-economic baseline studies indicate that locally harvested fish are not a significant component of the local economy or diet. Potential mitigation options such as restricting fishing by plant workers would be of questionable success. Based on the lack of quantifiable data, effects are considered low, with a long-term negative consequence (Table C3.3-8).

Table C3.3-8 Residual Impact Classification for Effects on Artisanal Fisheries

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FAH-3: What effect will the project have on subsistence fisheries?							
Fishing levels and fish availability							
construction	negative	low	local	short to long-term	no	low	low
operations	negative	low	local	medium-term	no	medium	low
closure	positive	low	local	long-term	no	medium	unknown
Change in fish health and condition							
operations	neutral	low	local	long-term	no	medium	low
closure	positive	low	local	long-term	yes	medium	low

Changes to fish health and condition could occur on a local level due to water quality downstream of the mine area being affected by:

- Increased sediment entrainment during instream construction activities.

- Accidents and spills into waterbodies.
- Sewage effluent discharges.
- Deposition of air emissions into local waterbodies.
- Seepage or infiltration of contaminants from the mine area.

Mitigation measures related to sediment input, air emissions, surface water flow and water quality will limit these changes to accepted international standards. These mitigation measures will also be monitored. The effects on fish health and condition are considered low after mitigation.

Contaminants in the water could have negative consequences for people eating fish due to:

- Existing contaminant loading (e.g., arsenic [Section B2.3-I]) from natural sources, ore-grade materials, pesticides or herbicides, or other unidentified sources.
- Potential incremental changes (tissue contaminants or fish health) to the condition of fish used for subsistence purposes.
- Increased consumption of affected fish.

Baseline fish tissue collected from a locally exploited *Barbus* sp. population on the lower Dipeta River displayed elevated levels of several metal contaminants, including arsenic, exceeding guideline levels for consumption. This suggests potential concern for human health. The assessment was limited to a small number of fish of one species, from a single location. Consequently, the characterization of contaminant levels within the LSA is incomplete and the effects and environmental consequence cannot be accurately predicted.

Impact Analysis

Residual impacts of changes to the informal fisheries as a result of the TFM project mine site construction, operation and closure are summarized in Table C3.3-8.

Prediction Confidence

The use of aquatic resources within the immediate mine disturbance area is moderately well understood based on observation during field programs. The level of information on specific use and extent of harvest of aquatic resources in the downstream and remaining LSA and RSA is limited due to the absence of additional seasonal data. The prediction confidence for impact ratings for fish and invertebrate communities 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 communities downstream is considered low.

The potential for subsistence fish food contamination appears low if all design and mitigation objectives are met. The present baseline contaminant loading mechanism (specifically for arsenic) and characterization of contaminant levels is poorly understood, making the effects and environmental consequence difficult to accurately predict. Based on the geochemical characterization program, arsenic behavior in the area can be summarized as follows:

- Arsenic concentrations in ore and waste rock from Kwatebala that have been tested are higher than average crustal values.
- Leach testing shows that arsenic leachability from waste rock is low (below detection limits to a few parts per billions), so the likelihood of arsenic mobilizing to the local environment is very low.
- Arsenic leachability from ore is slightly higher than for waste rock though still low.

Monitoring

Operation

- Tissue contaminant levels in selected fish species and populations used by subsistence fisheries will be monitored with a limited program in catchments associated with the development to confirm the performance of mitigation measures.

Closure

- Aquatic habitat characteristics will be monitored to assess the development and success of closure mitigation measures.

C3.3.3.7 Key Question FAH-4

Key question FAH-4 is: How can the project have a positive effect on aquatic habitat and subsistence fisheries?

Linkage Evaluation

Positive, long-term effects to fish and aquatic resources can be obtained if habitat is protected or created. Positive effects can also result from the TFM supplemental fish tissue contaminant monitoring. In addition to confirming mitigation performance, the monitoring program can be used to identify historic

sources of contamination in the RSA catchments, and therefore assist with an education and local public health protection strategy.

Assessment Methods

In general, assessment methods are the same as for FAH-1 to FAH-3. Based on the current condition of aquatic habitat, fish populations and resource use in the LSA and RSA and potential aquatic features in the LSA at closure, possible long-term benefits from the project for sustainability were assessed.

Mitigation

Mitigation measures addressed within the key questions, and particularly within key question FAH-4, are focused on protecting the ecosystem (which relates to human health). At closure, mitigation measures provide additional sustainable fish habitat, which will also benefit artisanal fisheries.

Additional specific measures which can aid the sustainability of the project are:

- Include riparian habitat conservation themes in any local environmental education programs that are developed for the TFM project.
- Provide assistance to the local government for watershed planning/land use zoning (Section C3.1).
- Develop environmental awareness programs to protect the health of the local population by identifying the health risk from existing fish food sources in the development area

Results

Successful protection of fish and aquatic habitats and successful development of fisheries at closure will enhance the local socio-economic sustainability and human health at closure. Environmental awareness education could have a high magnitude of benefit to the region.

Impact Analysis

Residual impacts for sustainability consequence are medium positive for environmental awareness education (Table C3.3-9). The sustainability consequence for catchment planning is predicted to be low to medium positive.

Table C3.3-9 Residual Impact Classification for Sustainability

Magnitude	Span or Reach	Duration	Probability of Success	Potential Sustainability Consequence
Key question FAH-4: How can the project have a positive effect on aquatic habitat and subsistence fisheries?				
Environmental awareness education				
high	half the community[(a)]	long-term	medium	moderate
Assistance with catchment planning				
moderate	half the community[(a)]	long-term	low/medium	low/moderate

[(a)] Interested people from local communities.

Prediction Confidence

Positive impacts will depend upon the implementation of proposed mitigation measures and the success of ecosystem restoration or development in the area. Prediction confidence is medium for achieving positive benefits to aquatic habitat and sustainability of fisheries.

Monitoring

Monitoring is described in the previous sections. No specific monitoring is proposed for key question FAH-4.

C3.3.4 CUMULATIVE EFFECTS ASSESSMENT

Linkage Evaluation

The cumulative effects assessment is based on project expansion from copper production of 115,000 tonnes per year to a 400,000 tonnes per year. The linkage components for the cumulative effects assessment will be similar or the same as those identified for the base project (Figure C3.3-1). The validity of the linkages described for the impact assessment could change depending on the final development conditions and design for the expansion. The physical extent of catchment modifications would increase considerably with additional areas being mined and additional areas required for tailings storage facilities, waste rock facilities and processing plants.

Assessment Methods

Detailed plans for the additional development of the project expansion to 400,000 tonnes per year are not yet available. The general concept for the expanded development was reviewed according to known baseline conditions for fish and aquatic habitat. Professional experience (in relation to the changes in the catchments as they may affect aquatic habitat caused by mining, plant sites,

waste rock facilities, quarries and linear developments) was used to develop a comprehensive understanding of the potential effect of an expanded project. Principles developed for closure plans and other project goals for long-term mitigation of effects were used to develop an assessment of long-term impacts.

Mitigation

In addition to expansion of the mitigation measures proposed for the base case development, a 400,000 tonnes per year project would require a more detailed plan for catchment restoration. This is due to the greater level of impact on the Dipeta catchments by the expanded project.

Results

The effects on fish and aquatic habitat with an expanded mining project would be similar but greater in magnitude than those predicted for key questions FAH-1 to FAH-3. Larger and permanent effects would occur due to the development of expanded mine pits, waste rock areas and new tailings storage areas. Fish and aquatic habitat within several catchments associated with the base case, in particular the Shimpidi catchment, would be affected by the expansion. In addition, watercourses closer to Fungurume may be affected by mine operations. The Shimpidi catchment, which contains some of the most ecologically intact aquatic ecosystems in the LSA, will experience a large loss, displacement and fragmentation of aquatic habitat. The lower Shimpidi River displayed signs of considerable artisanal fishing use (fish traps) and some direct effect on subsistence food fisheries can be expected.

Impact Analysis

For the cumulative effects case, impacts will occur across much of the LSA and likely in additional catchments outside of the LSA, such as the Fungurume hills. This expanded project would affect considerably more drainage area than the base project case and potentially impact a much larger aquatic resource or subsistence fishery. The environmental consequence is expected to be moderate (Table C3.3-10).

Table C3.3-10 Residual Impact Classification for the Cumulative Case

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question $FAH_{(ce)}$-1: What effect will the expanded project have on aquatic habitat?						
negative	moderate	local and regional	Long-term	no	medium	moderate

ce = Cumulative effects.

Prediction Confidence

The baseline status of fish and aquatic habitat in the LSA is moderately understood. Information concerning the effects of an expanded (400,000 tonnes per year) mining project is limited. Only a general understanding of the effects of an expanded project can be presented. The prediction confidence for this assessment is low to moderate, depending on the linkage.

Monitoring

A similar monitoring program as described in key questions FAH-1 to FAH-3 should be implemented. This monitoring program should be expanded locally and regionally for the expanded project.

C3.3.5 CONCLUSIONS

Generally, low environmental consequences (ranging from low to moderate) for local aquatic habitat and fish species are predicted to occur due to residual impacts from construction and operation of the mine during the base operation (Table C3.3-11).

Table C3.3-11 Summary of Residual Impact Classification for Fish and Aquatic Habitat

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FAH-1: What effect will the project have on aquatic habitat?						
negative to positive	low to high	local and regional	short to long-term	yes/no	low to medium	low to high
Key question FAH-2: What effect will the project have on fish and aquatic biota abundance?						
negative to positive	low to high	local	short to long-term	yes/no	low to medium	low to moderate
Key question FAH-3: What effect will the project have on subsistence fisheries?						
negative to positive	low	local and regional	medium to long-term	yes/no	low to medium	low

Downstream impacts on aquatic habitat and biota are expected to be largely mitigated, with low to moderate consequences. The effects on informal harvest of fish are also expected to be of low consequence during the base case.

Positive impacts are anticipated for aquatic habitats at closure. These positive impacts may be of low or negligible consequence because of the limited amount of watercourse or waterbody habitat being restored or developed. Upon closure, positive impacts may occur from development of potential artisanal fisheries and re-establishment of suitable fish species.

Sustainability Effects

Sustainability initiatives such as increasing environmental awareness, fish culture and catchment planning could have a positive medium sustainability consequence (Table C3.3-12).

Table C3.3-12 Summary of Sustainability Assessment for Fish and Aquatic Habitat

Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key question FAH-4: How can the project have a positive effect on aquatic habitat and subsistence fisheries?				
moderate - high	half the community	long-term	low/medium	low to moderate

Cumulative Effects

Effects from the expanded project are expected to be much higher than effects from the project (Table C3.3-13). A more detailed catchment restoration plan would be required if the expansion were to take place.

Table C3.3-13 Summary of Residual Cumulative Impact Classification for Fish and Aquatic Habitat

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question FAH-1: What effect will the project have on fish and aquatic habitat?						
negative	moderate	local and regional	long-term	no	medium	moderate

ce = Cumulative effects.

C3.4 NATURAL HABITATS AND BIODIVERSITY

C3.4.1 Introduction

This section presents the environmental assessment for the effects of the project on natural habitats and biodiversity as per the project's terms of reference (Appendix E8). The information presented includes details on:

- Potential issues regarding changes to natural habitats and biodiversity.
- Project activities that may affect natural habitats and biodiversity.
- Mitigations incorporated in the project design for these impacts.
- Methods used for the analysis of biodiversity effects.
- Impact assessment approach and results for key biodiversity issues.
- Sustainability assessment approach and results for key natural habitats and biodiversity issues.
- Identified measures relating to natural habitats and biodiversity to promote long-term economic and social sustainability in the project area.

This section is organized as follows:

- Section C3.4.2 describes the study areas.
- Section C3.4.3 discusses the impact assessment and sustainability assessment approach and results.
- Section C3.4.4 provides the cumulative effects assessment.
- Section C3.4.5 discusses the conclusions of the assessment.

Baseline information, concerning natural habitats and biodiversity, has been provided in Section B3.4. The analyses presented in this section are also supported by data derived from separate baseline treatments of flora in Section B3.1, fauna in Section B3.2 and fish and aquatic habitat in Section B3.3. A strategy for conservation of copper-cobalt flora (Appendix D3.1-I) and a flora biological diversity action plan (BDAP) also were prepared (Appendix D3.1-II). These appendices describe detailed conservation efforts, mitigation strategies and success/performance monitoring for the flora conservation program.

A glossary of terms and acronyms used is provided at the back of this volume.

C3.4.2 Study Areas

The study areas for the natural habitats and biodiversity impact assessment are the same as those for the baseline.

The Regional Study Area (RSA) is the same as that for flora and fauna and is shown in Figure C1.6-1. The RSA is of sufficient size to provide a sound basis for the assessment of impacts from the cumulative effects case (Section A5.5.1).

The Local Study Area (LSA) is the same as that for flora and fauna and is as shown in Figure C1.6-1. The LSA contains a representative cross section of all of the habitats that occur in the concession, and contains all areas that may be directly impacted by the project.

C3.4.3 Impact Assessment

C3.4.3.1 Issue Scoping

The anticipated key issues relating to natural habitats and biodiversity are:

- Direct or indirect impacts on rare locally endemic, threatened or endangered species.
- Impacts on rare natural habitats or habitats supporting high species richness.
- Fragmentation of rare natural habitats or habitats supporting high species richness.

Issues noted during the public consultation process (Section A6 and Appendix E6) include concerns about the loss of forested areas and plant and animal species, including any plants of potential medicinal value on Kwatebala Hill.

Some issues directly related to biodiversity, especially biodiversity at the species level and basic analyses for the loss of natural habitats, have been presented in Sections C3.1 (flora), C3.2 (fauna), and C3.3 (fish and aquatic habitats). This section presents a combined analysis of those results and conducts a more detailed analysis of habitat fragmentations.

C3.4.3.2 Key Questions and Indicators

The key questions for natural habitats and biodiversity are listed in Table C3.4-1.

Table C3.4-1 Key Questions for Natural Habitats and Biodiversity

Impact Assessment
HB-1 What effect will the project have on biodiversity at the species level?
HB-2 What effect will the project have on natural habitats and biodiversity at the landscape level?
Sustainability Assessment
HB-3 How can the project influence natural habitats and biodiversity to have a long-term positive effect?

Indicators relating to natural habitats and biodiversity are shown in Table C3.4-2. Some of these indicators are addressed in this section, while others are addressed as noted in other parts of the biology environmental and socio-economic assessment (ESIA).

Practically, in this environmental and social impact assessment (ESIA), the amount of land affected, managed or reclaimed by the project in a variety of habitats with defined levels of species diversity and ecosystem connectivity and integrity will be measured as indicators. Changes in the mean size of habitat patches and changes in the distance between habitat patches will also be measured. Finally, species richness and the number of World Conservation Union (IUCN) Red List species or their equivalent will be used as indicators for habitats that are managed or reclaimed.

This ESIA also addresses how the International Finance Corporation's (IFC's) performance standards for biodiversity conservation and natural resource management are met. The key standards relevant to the project are listed in Table C3.4-3.

C3.4.3.3 Assessment Criteria

Assessment criteria for natural habitats and biodiversity are presented in Table C3.4-4. The screening system for sustainability consequence is provided in Section A5.

C3.4.3.4 Key Question HB-1

Key question HB-1 is: What effect will the project have on biodiversity at the species level?

Table C3.4-2 Indicators for Natural Habitats and Biodiversity

Global Reporting Initiative Indicators [a]		ESIA Indicators	Key Habitats Considered[b]	Sections in Which Indicator is Addressed
EN 6	location and size of land owned, leased, or managed in biodiversity-rich habitats	• total amount of land in each vegetation type affected by the project • changes in mean size of habitat patches • changes in distance between habitat patches	1,2,3,4	C3.1 C3.4
EN 7	description of the major impacts on biodiversity associated with activities and/or products and services in terrestrial, freshwater and marine environments	• effects on faunal demography	1,2,3,4,5,6,7,8	C3.2
EN 20	water resources and related ecosystems/habitats significantly affected by use of water	• water quality section results • key habitats affected by changes in volume and quality of water	1,2,3,4,5,6,7,8	C3.2
EN 23	total amount of land owned, leased, or managed for production activities or extractive use	• size of mining lease • total amount of land in each vegetation type affected by the project	1,2,3,4,5,6,7,8	C3.1
EN 26	changes to natural habitats resulting from activities and operations and percentage of habitat protected or restored. identify type of habitat affected and its status	• total amount of land in each vegetation type reclaimed • number of exotic or pest species in each managed, restored or reclaimed habitat (can be used for monitoring)	1,2,3,4	C3. 1 C3. 2 C3.4 C3.5
EN 27	objectives, programs, and targets for protecting and restoring native ecosystems and species in degraded area	• total amount of land managed or reclaimed	1,2,3,4	C3.1 C3.4
EN 28	number of World Conservation Union (IUCN) Red List species with habitats in areas affected by operations	• species richness and number of IUCN Red List species in land managed or reclaimed	1,2,3,4	C3.1 C3.2 C3.3 C3.4
EN 29	business units currently operating or planning operations in or around protected or sensitive areas	• predicted influence on fauna in the copper-cobalt and wetland habitats and in populated areas	2,4,6	C3.5 C3.2
EN 32	water sources and related ecosystems/habitats significantly affected by discharges of water and runoff	• water quality section results • key habitats affected by changes in volume and quality of water	aquatic habitats (streams, wetlands)	C3.1 C3.2 C3.3
EN 34	significant environmental impacts of transportation used for logistical purposes	• predicted fauna mortality due to traffic in the habitats in the RSA	1,2,3,4,5,6,7,8	C3.2

[a] Global Reporting Initiative (GRI 2005b).

[b] Key Habitats Considered.

Legend:

1 gallery forest
2 copper-cobalt steppe-savannah
3 miombo woodland (intact)
4 copper-cobalt rock outcrop
5 miombo woodland (degraded)
6 wetlands
7 agricultural mosaic
8 disturbance areas

Table C3.4-3 International Finance Corporation Standards and Location Addressed

Standard[(a)]	Section(s) in Which Standard is Addressed
In areas of modified habitat, the project will exercise care to minimize the conversion or degradation of such habitat.	Section C3.4.3.5
In areas of natural habitat, the project will not significantly convert or degrade such habitat, unless: -there are no technically feasible alternatives. -the overall benefits of the project outweigh the costs including those to biodiversity. -any conversion or degradation is appropriately mitigated.	Section C3.4.3.5
Mitigation will be designed to achieve no net loss of biodiversity where feasible, and may include: -post-operation restoration of habitats. -offset of losses through the creation of ecologically comparable areas. -compensation to direct users of biodiversity.	Section C3.4.3.5 (habitats) Section C4.1 (land use / users of biodiversity)
In areas of critical habitat (including areas of high biodiversity value, such as habitat required for the survival of endangered or critically endangered species, if found to exist in the LSA), the following will be met: -there are no significant adverse impacts on the ability of the critical habitat to support established populations of critically endangered or endangered species. -there is no reduction in the population of any recognized critically endangered or endangered species. -any lesser impacts will be addressed as per the standard in the above row.	Section C3.4.3.5 Biological Diversity Action Plan, Section D3.1-II
The project will not deliberately introduce any alien species with a high risk of invasive behavior and will exercise diligence to prevent accidental introductions.	Section C3.4.3.4

[(a)] IFC standards under Performance Standard 6, Biodiversity Conservation and Natural Resource Management. IFC (2006c).

Table C3.4-4 Impact Description Criteria for Natural Habitats and Biodiversity

Direction[a]	Magnitude[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
neutral: no change in biodiversity indicators **negative:** a change in biodiversity indicators resulting in lower habitat connectivity and lower habitat integrity **positive:** a change in biodiversity indicators resulting in higher habitat connectivity and higher habitat integrity	**negligible:** no measurable effect on biodiversity indicators (less than 1%) **low:** less than 10% changes in biodiversity indicators **moderate:** 10 to 20% change in biodiversity indicators **high:** greater than 20% change in biodiversity indicators	**local:** effect restricted to the LSA **regional:** effect extends beyond the LSA	**short-term:** less than 3 years **medium-term:** 3 to 20 years **long-term:** greater than 20 years	reversible or irreversible	**low:** occurs once or rarely **medium:** occurs intermittently **high:** occurs continuously

[a] Direction: positive or negative effect for measurement indicators as defined for the specific component.

[b] Magnitude: degree of change to analysis indicator.

[c] Geographic Extent: area affected by the impact.

[d] Duration: length of time over which the environmental effects occurs. Considers a two-year construction period and a 20-year operations period.

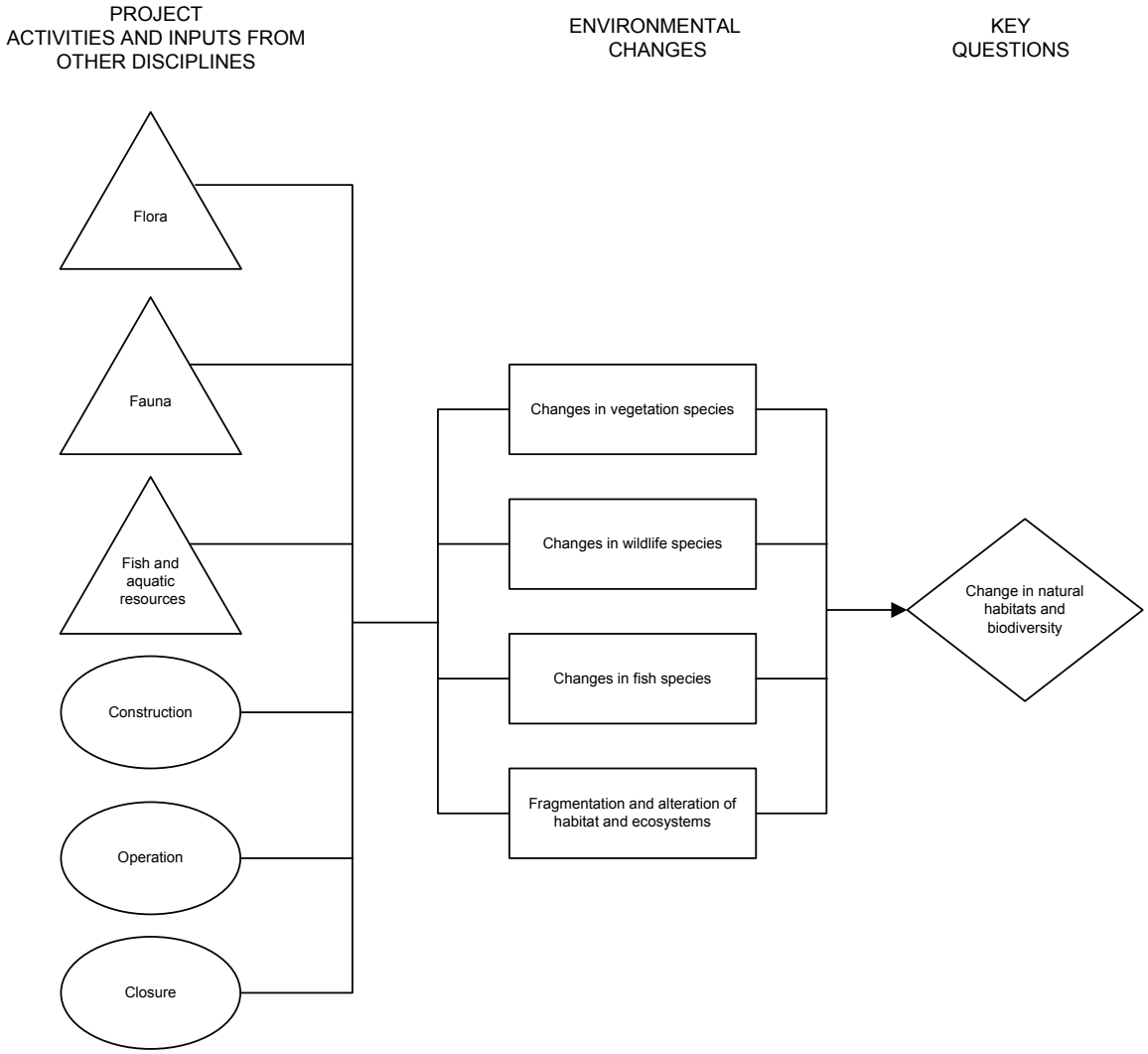
[e] Reversibility: effect on the resource (can or cannot be reversed).

[f] Frequency: how often the impact occurs.

Linkage Evaluation

At the species level, impacts on flora, fauna, and fish and aquatic resources are all valid linkages as described in Sections C3.1, C3.2 and C3.3, respectively. Project activities during the construction, operation and closure phases may all have effects (Figure C3.4-1).

Figure C3.4-1 Natural Habitats and Biodiversity Linkage Diagram



Assessment Methods

Baseline data for species richness and IUCN conservation status for plants and wildlife were used as indicators of the importance and quality of species biodiversity for natural habitats in the LSA and RSA (Section B3.4). The IUCN Red List is an internationally accepted database of species at various levels of vulnerability, ranging from "Critically Endangered" to species of "Low Concern". The categories of species considered to be at elevated risk for the purposes of this ESIA are the three most threatened categories within the IUCN list: Critically Endangered, "Endangered" and "Vulnerable". The level of loss of

habitats with high levels of biodiversity and/or Red-listed species is measured to assess impacts on species-level diversity.

It should be noted that the IUCN has yet to study data on the rare flora of the LSA and therefore has not listed any of these species in terms of a formal conservation/threat status. There are a total of 12 species that were listed as potential IUCN 'equivalent' species of concern (Section B3.1) within the LSA (Table C3.1-8). Nine of these species will be directly affected by the TFM project. Three of these meet the potential status of critically endangered due to limited known distributions.

Fragmentation analysis of the LSA was done using geographic information system (GIS) analysis for baseline conditions, and then again considering the impact of the project. Direct impacts of the project on species-level biodiversity are partly addressed in Sections C3.1 (flora), C3.2 (fauna) and C3.3 (fish and aquatic habitats). In this section, species-level biodiversity is assessed through the changes in area, composition and spatial configuration of the natural habitats on the landscape.

The potential impact of the project on biodiversity indicators (metrics such as level of fragmentation) was estimated by using the following equation. The relative difference between project (during the project) case and baseline (pre-project) landscape metrics was calculated as a percentage:

Equation 1. (project case value – baseline value) / baseline value

Impacts are presented at the scale of the LSA, while impacts if viewed at a larger scale are discussed qualitatively.

Preliminary closure plans (Section D5) and other project goals for long-term mitigation of effects were used to develop an assessment of long-term impacts. Impact levels were predicted both for the maximum impact case during operation, and for the fully mitigated case following reclamation.

Mitigation

The following mitigation measures will be employed to minimize impacts on biodiversity at the species-level. Species-specific mitigation will also be carried out as described in Sections C3.1, C3.2 and C.3.3 for flora, fauna and fish and aquatic habitats.

- The analysis of alternatives (Section A3) has resulted in facility design modifications for the processing plant, tailings storage facility, construction

camps and linear access routes aimed at reducing impacts. These included grouping facilities together to minimize fragmentation impacts.

- Common and/or existing corridors will be utilized for powerlines and pipelines.
- Some off-site representative portions of the copper-cobalt flora habitats will be protected in plant micro-reserves (PMRs), ecosystem reconstruction areas or conservation areas (as described in more detail in the BDAP (Appendix D3.1-II).
- If a site with rare endemic species is to be impacted, the rare endemic flora will be managed according to the measures described in the BDAP (Appendix D3.1-II), which may include translocation to other habitats.
- Other species-specific mitigation as described in Sections D3.1.12, D3.1.13 and D3.1.14.
- One or more areas with documented copper-cobalt flora or the potential to support this rare flora will become natural reserves and areas for copper-cobalt flora ecosystem construction.
- Non-native species will not be introduced for reclamation unless they are required for local land uses, are documented as being non-invasive by the scientific staff identified in the BDAP (Appendix D3.1-II) and their use is approved by stakeholders. Weed and pest monitoring and control programs will be implemented in project areas to prevent accidental introductions of exotic invasive species.
- Reclamation will occur progressively as practical and feasible during the operations phase, and will be completed in the closure phase. Reclamation will help to reduce the changes that occur at the project sites during operations, and help to restore or enhance topographic and biological diversity. Because of the high social and biodiversity values of gallery forest areas, the project will reclaim an equivalent area to that affected during the construction and operation phases. Based on results of the BDAP research program, copper-cobalt flora will also be reclaimed on portions of the development site. The BDAP identifies strategies for assessing these species for their reclamation potential. However, biodiversity restoration will not be the main goal at all project reclamation sites, unless public consultation indicates that this is the preferred post-mining use for the reclaimed landscape.
- Equivalent areas of gallery forests to those impacted by changing hydrogeologic conditions will be restored elsewhere.

Results

The mine, tailings storage facility and processing plant site together create a new area of disturbance that has the potential to affect species in a variety of habitat types. Smaller effects will occur due to the development or enhancement of

linear transport routes, the powerline and the limestone quarry site. Many of these areas will subsequently be reclaimed, but some will be altered for the long term. Additional areas will be affected by increased land use, such as hunting, with increases in the regional population.

Key indicators for species-level biodiversity is the amount and patch size of biodiversity-rich habitats affected (Table C3.4-2). Decreased habitat amount and patch size is associated with decreased population sizes. 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). Gallery forest, intact miombo woodlands and the two copper-cobalt habitat types (rock outcrops and savannah) have been ranked as the four most biodiversity-rich habitat types (Section B3.4). The project will directly impact approximately one hectare of gallery forest (three percent of this habitat present under baseline conditions in the LSA) and may indirectly impact an additional 12 hectares within the Kasana and Shimpidi drainages due to lowering of the groundwater table (potentially an additional 32 percent of this habitat type). The project will also directly impact 519 hectares of intact miombo forest (16 percent of baseline amounts); 185 hectares of copper-cobalt steppe-savannah (37 percent of baseline amounts); one hectare of wetlands (four percent of baseline amounts); and five hectares of copper-cobalt rock outcrops (47 percent of baseline amounts). These percentages represent the total footprint of the project without consideration of reclamation (Table C3.4-5) and therefore are considered a worst case scenario.

Table C3.4-5 Change in Landscape Metrics for Maximum Development in Relation to Species-Level Biodiversity Rankings

Natural Habitat Type	Baseline Species-Level Biodiversity Ranking	Change in Total Area (%)	Change in Mean Patch Area (%)	Change in EMNN[(a)] (%)	Change in Total Edge to Area Ratio (%)
gallery forest	1	-3[(b)]	-3	+1	+1
copper-cobalt steppe-savannah	2 (tie)	-37	-11	+104	-15
intact miombo woodland	2 (tie)	-16	-23	+16	-1
copper-cobalt rock outcrop	4	-47	+74	+977	-15
degraded miombo woodland	5	-31	-41	-5	+18
wetlands	6	-4	+20	-90	-2
agricultural mosaic	7	-14	-42	-21	+17

(a) Euclidian Mean Nearest Neighbor. Negative changes indicated average patches are now closer together, which may occur due to fragmentation of existing patches into new sets of patches that are very near one another.

(b) Does not include indirect hydrologic impacts, which will be fully compensated for through restoration.

The loss of high proportions of the copper-cobalt steppe-savannah and complexes containing copper-cobalt rock outcrops are of greatest concern. Section C3.1 describes which plant species of concern are likely to be affected by this impact.

Considering the full impact of the project prior to reclamation, gallery forests are affected by slightly declining total area (three percent) and patch size (three percent) and slightly increasing distance between patches (one percent), and an overall increase in the edge to area ratio of these patches (one percent) (Table 3.4-5). Gallery forests also occur in many areas in the region outside the LSA and throughout Africa, meaning that impact-percentages would be much smaller when viewed at a larger scale. Although the project is largely successful in avoiding gallery forest impacts, all of the measured indicators suggest the TFM project will have a slight effect in reducing the integrity and connectivity of this habitat type. To mitigate indirect hydrologic impacts, baseflows in the Kasana, Sokalwela and Shimpidi Rivers will be augmented with access pits dewatering water as available. Due to uncertainty associated with the success of this mitigation an equivalent area of gallery forest habitats to those that are dewatered within the project's core of depression will be restored along with degraded habitat within the concession area. Overall species diversity in the gallery forest should not be affected in the long term. Because it is a complex ecosystem, reclamation may not fully restore all species in the LSA.

In addition to a large loss in total area (37 percent), copper-cobalt steppe-savannah habitats will undergo a slight decline (11 percent) in patch area, and a large increase (104 percent) in the distances between the patches during the operations phase. Increasing the distances between patches will result in greater insularity of patches and decreased genetic transfer of plants and animals that have trouble dispersing over large distances. There will also be a decline in patch edge to area ratio (15 percent), meaning that the remaining patches are shaped such that there is less exposure to edge areas; this occurs due to the elimination of some marginal edge copper-cobalt savannah during operations. Overall species diversity may decline somewhat in the copper-cobalt steppe-savannah in the LSA, due to loss of habitat areas that have the potential to contain rare species. This effect will occur for flora but not fauna, as no animal species have been found to be solely dependent on this habitat. On a larger scale, copper-cobalt steppe-savannah habitats can likely be found throughout the Lufilian Arc, although this habitat is not be common elsewhere in Africa. The preservation of PMRs, creation of a managed area, ecosystem reconstruction and reclamation of these habitats will partially offset these impacts to biodiversity.

There will be a marked (23 percent) decline in the area of patches of miombo woodland during operations, and a slight increase (16 percent) in distance between intact miombo woodland patches. Out of the four most biodiversity-rich

habitats, this woodland will be the most affected by the project. However, this habitat type is abundant regionally. The World Wildlife Fund (WWF 2001) estimates the total size of miombo woodland at 3.6 million square kilometers in Africa, making the impact of the project inconsequential at this large scale. This habitat can also be reclaimed in large part, making the relative impact of the project on biodiversity at the species level small.

There will be a 47 percent decline in total area of copper-cobalt rock outcrop in the LSA. Despite this, there is a 74 percent increase in mean patch area because a few, large patches are left behind. However, there is a 977 percent increase in mean distance between patches, leading to increased genetic isolation of the species in these habitat patches. Even when viewed on a very large scale (Africa), this impact is large, because these habitat types are limited to the copperbelt. At a species level, this is an important impact to the local flora. However, no threatened or endemic animal species are dependent on this habitat. Therefore, there is no risk of local extirpation of fauna on the copper–cobalt rock outcrops as a result of habitat loss. Efforts to reduce the impact will be made through active management of PMRs and ecosystem reconstruction in new areas.

Wetlands, which are limited in number in the LSA and of high importance for specific species as described in the fauna baseline, are impacted slightly by the project. The total area of wetlands in the LSA drops by four percent due to the removal of one small wetland. The mean area per patch increases by 20 percent. Because the affected wetland was far from all other wetlands, the average distance between wetland patches will decline by 90 percent. Species-specific impacts for fauna are described in Section C3.2.

The degraded miombo woodlands and agricultural mosaic habitat types will undergo declines in total area (31 percent, 14 percent) and patch area (41 percent, 42 percent), and both will have increased distances (five percent, 21 percent) between patches in the operations phase. However, these changes are not used as key indicators of overall species biodiversity impact because these habitats are of relatively low importance for species-level biodiversity.

Land use impacts, including increased hunting with a rise in regional population, will reduce fauna diversity at the species level above and beyond the loss due to habitat impacts.

Stream habitats are also generally of low importance in relation to species-level biodiversity. As stated in Section C3.3 (fish and aquatic resources), these habitats are generally degraded and the species that are present in the LSA are found elsewhere in the RSA and beyond. However, downstream of the TFM project on

the Shimpidi River, relatively intact canopy forest that still supports an ecologically intact ecosystem.

Impact Analysis

The changes to gallery forest during operations will include a three percent decline in total area and a three percent decline in area per patch, and potentially additional indirect impacts, which however will be fully compensated for through restoration. These changes will not necessarily be associated with any decline in species diversity, but due to the possibility of such an effect, the impact is considered low during operations. The effect will be local in extent (in the LSA only), medium term in duration and partially reversible because reclamation will occur during and immediately after the operation phase. Impacts will be moderate in frequency for the length of the operation phase. The environmental consequence during this phase is low (Table C3.4-6).

Table C3.4-6 Residual Impact Classification for Key Question HB-1

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question HB-1 What effect will the project have on biodiversity at the species level?							
Species diversity in gallery forest							
construction and operation	negative	low	local	medium-term	no[(a)]	moderate	low
closure	negative	low	local	long-term	no[(a)]	low	low
Species diversity in copper-cobalt steppe-savannah							
construction and operation	negative	high	local	medium-term	no[(a)]	high	high
closure	negative	moderate	local	long-term	no[(a)]	low	moderate
Species diversity in intact miombo woodland							
construction and operation	negative	low	local	medium-term	no[(a)]	high	low
closure	negative	low	local	long-term	no[(a)]	low	low
Species diversity in copper-cobalt rock outcrop							
construction and operation	negative	high	local	medium-term	no[(a)]	high	high
closure	negative	moderate	local	long-term	no[(a)]	low	moderate

[(a)] Partial reversibility with reclamation.

At the time of project closure, impacts on gallery forest are expected to be fully mitigated through reclamation and/or environmental compensation. Because it will take time for reclaimed habitats to support a full complement of species, there will be some residual impacts. Residual impacts after mitigation will be low in magnitude and therefore low in environmental consequence (Table C3.4-6).

Copper-cobalt steppe-savannah patches will be less numerous, of slightly smaller size and will have greater distances between them during the operations phase. The loss of 37 percent of this habitat type indicated a potentially high impact on species diversity, due to the known presence of rare and endangered species within the steppe-savannah. The effects will be local in extent, medium term in duration and partially reversible. A high environmental consequence for biodiversity is expected in the operation phase.

After closure, the residual impact on copper-cobalt steppe-savannah will be moderate in magnitude, with the assumption of successful protection of PMRs and ecosystem restoration and reclamation and re-introduction of rare species as feasible, as described in the BDAP (Appendix D3.1-II). The residual impact will be local in extent, long term in duration and reversible. The overall environmental consequence will be moderate.

Miombo woodland patches will decline in total area by 16 percent and in area per patch by 23 percent during operation. The distance between intact miombo woodland patches will increase by six percent. These changes will have a relatively small effect on species-level biodiversity due to the common nature of the habitat type in the region; although it may affect local species abundance in some cases, the overall magnitude is predicted to be low during operations.

After closure, reclamation will help to reduce species-level biodiversity impacts in miombo woodlands. However, some long-term effects will occur as species gradually return to the reclaimed habitats. The impact is predicted to be low.

Copper-cobalt rock outcrop habitats will be reduced in total area by approximately 47 percent during the operation phase, and remaining patches will be slightly smaller, on average, with much longer distances between them. Because of the high incidence of rare and threatened species in the copper-cobalt rock outcrops, this impact is considered high in magnitude. It is local in extent, medium-term in duration and is partially reversible. Impacts will occur at a high frequency during the operations phase. The environmental consequence for species-level biodiversity is high.

At closure, the purposeful reconstruction of such habitats in new areas, if successful, will reduce the residual impact of the project on species-level biodiversity to moderate in magnitude. Reclamation of copper-cobalt outcrops on low-grade ore stockpiles and biological gardens (Section C3.1) may also be successful. Tailings and mine areas will present some challenges for reclamation but will be revegetated as feasible to scrub and other habitats. The effect will be local in extent, long term in duration, partially reversible, and of low frequency after closure. The environmental consequence will be moderate.

During operation and after closure, the effect of hunting and trapping within the RSA is predicted to have a high consequence for residual faunal biodiversity. This impact is described in Section C3.3.

Prediction Confidence

The effects of the project on species-level biodiversity are moderately well understood. Limitations to the prediction confidence include:

- The complexity of ecological systems (making it difficult to determine the fate of species in partially fragmented or slightly smaller habitat areas).
- Presently limited data (i.e., at the time of impact prediction) on the resilience and locations of each of the endangered or threatened species identified in the flora and fauna assessments (Sections C3.1 and C3.2, respectively).
- By necessity, not all types of species (such as insects and lichens) have been fully inventoried in the LSA, meaning that some additional, rare species may be present.
- Uncertainty with respect to reclamation (can all types of habitat be successfully reclaimed or constructed in the post-closure landscape, or in newly developed natural reserves?).

The prediction confidence for this assessment is therefore moderate.

Monitoring

The monitoring program for biodiversity is composed of flora and fauna components, as described in Sections C3.1, C3.2 and C3.3 and the environmental action plans in Section D3. Changes to ecosystem process and function will focus on abiotic variables such as water quality and air quality, as described in Sections C2.12 and C2.8, respectively. Monitoring of the effectiveness of natural reserves and of exotic species is described in the flora section, C3.1. Monitoring

of the effectiveness of reclamation success is described in Sections C3.1 and D5. No additional monitoring is proposed specifically for this key question.

C3.4.3.5 Key Question HB-2

Key question HB-2 is: What effect will the project have on natural habitats and biodiversity at the landscape level?

Linkage Evaluation

Landscape-level biodiversity relates to the diversity, structure, function and spatial distribution of ecological communities (or habitats) within a complex that includes many kinds of habitats, including man-made habitats. Landscape-level impacts including the alteration and fragmentation of natural habitats is a valid impact linkage, because the project will result in the alteration and fragmentation of several kinds of natural habitat (Figure C3.4-1).

Assessment Methods

The assessment for landscape-level biodiversity effects focuses on the same habitats as key question HB-1, and assesses impacts using the same indicators for habitat intactness and connectivity, but key question HB-2 discusses what these impacts mean on the scale of the landscape. Baseline data for landscape-level habitat metrics including total area, number of patches, mean distance between patches, and total edge were calculated and used to rank the connectivity and intactness of natural habitats under baseline conditions in the LSA and RSA (Section B3.4). Fragmentation analysis of the LSA was conducted again for the project case (maximum impact scenario) using GIS analysis. Direct impacts of the project on biodiversity were assessed through the changes in area, composition and spatial configuration of the natural habitats on the landscape.

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:

Equation 1. (project case value – baseline value) / baseline value

Preliminary closure plans (Section D5) and other project goals for long-term mitigation of effects were used to develop an assessment of long-term impacts. Impact levels were predicted both for the maximum impact case during operation, and for the fully mitigated case following reclamation.

Mitigation

The following mitigation measures will be employed to minimize impacts on natural habitats and biodiversity at the landscape level:

- The project is designed within the smallest technically and environmentally feasible footprint size that meets the needs of the project.
- Common and/or existing corridors will be utilized for powerlines and pipelines.
- Existing rare natural habitats for copper-cobalt flora will be managed in several natural areas. Other areas will become natural parcels and areas for copper-cobalt flora ecosystem construction.
- Plant micro-reserves (PMRs) will be established to protect fragments of valuable habitat and associated species near areas being developed for mining (Section D3.1.12).
- Land will be progressively revegetated, as much as feasible, with native species during operation to reduce the area impacted and to partially reduce habitat fragmentation effects.
- Equivalent areas of gallery forests to those impacted by changing hydrogeologic conditions will be restored elsewhere.

Results

The mine, tailings storage facility, and processing plant site together create a new area of disturbance that has the potential to affect landscape biodiversity. Habitat fragmentation will occur due to the development or enhancement of linear transport routes and the limestone quarry site. Many of these areas will subsequently be reclaimed, but some will be altered for the long term.

Because the agricultural mosaic and degraded miombo woodlands are extensively modified, they are not used as indicators for potential biodiversity impacts (Table C3.4-2). Impacts to the remaining five major habitat types in Table C3.4-7 are introduced in Section C3.4.3.4 and discussed below in the context of landscape-level biodiversity. Table C3.4-7 presents the same indicators for impacts that were presented in Table C3.4-5, but Table C3.4-7 is in the order of rank for baseline habitat intactness, as ranked in the baseline Table B3.4-4.

Table C3.4-7 Change in Landscape Metrics for Maximum Development in Relation to Landscape-Level Biodiversity Rankings

Natural Habitat Type	Baseline Intactness/ Fragmentation Biodiversity Ranking	Change in Total Area (%)	Change in Mean Patch Area (%)	Change in EMNN[(a)] (%)	Change in Total Edge to Area Ratio (%)
agricultural mosaic	1	-14	-42	-21	+17
intact miombo woodland	2	-16	-23	+16	-1
copper-cobalt steppe-savannah	3	-37	-11	+104	-15
degraded miombo woodland	4	-31	-41	-5	+18
wetlands	5	-4	+20	-90	-2
gallery forest	6	-3[(b)]	-3	+1	+1
copper-cobalt rock outcrop	7	-47	+74	+977	-15

(a) Euclidian Mean Nearest Neighbor: Negative changes indicated average patches are now closer together, which may occur due to fragmentation of existing patches into new sets of patches that are very near one another.

(b) Does not include hydrologic impacts, which will be fully compensated for through restoration.

Intact miombo woodlands, copper-cobalt steppe-savannah, degraded miombo woodlands, gallery forests and copper-cobalt rock outcrop will all experience declines in total areas and declines in areas per patch during the operation of the TFM project. All except the degraded miombo woodland will experience increases in the average distance between patches, as well.

Wetlands are small in number and total area in the LSA but are important in that they increase landscape diversity and support species that would otherwise not be present. One mapped wetland occurs in the area of the project footprint. Impacts to this wetland will decrease the total area of wetlands in the LSA, increase the area per wetland patch and decrease the mean distance between wetlands in the LSA.

These project effects will work in combination with the impacts already occurring on the landscape under baseline conditions, which have gradually fragmented these habitats. In addition, the effect of increased population densities in the RSA will likely include greater habitat fragmentation.

The isolation of habitats can have effects on biodiversity as natural linkages between populations of plants and animals are interrupted (ICMM 2006; Debinsky and Holt 2000). Some species may have difficulty moving back and forth between patches (for example, between patches of gallery forest) if this involves traversing a large expanse of another habitat type or disturbed land.

Smaller, isolated populations of plant and animal species within patches are generally less resilient.

In addition, fragmentation tends to increase the prevalence of edge effects. Forest edge effects can include modifications in moisture, light and nutrient regimes (Kitchell et al. 1979; Kapos 1989; Saunders et. al. 1991; Brown 1993; Nichol 1994). For example, the edges of a habitat such as a miombo woodland may be altered in microclimate and species composition. Such edge effects also increase the prevalence of invasive species from other habitats which can out-compete and replace unique niches once held by native species within an ecosystem (Turner 1996; Debinski and Holt 2000). Mitigations for control of weeds should limit these effects.

Aquatic (stream) habitats are generally degraded in the LSA, one feature of specific interest in relation to habitat diversity is a tufa weir structure formed from calcium carbonate deposition in the Dipeta River at fishery site DTI (Section B3.3-5). This site will not be physically impacted by the TFM project. The impacts of the TFM project in relation to loss and fragmentation of stream habitat is discussed in Section C3.3.

Strategies for the protection and restoration of native ecosystems (habitats) both during and after completion of the TFM project are described in the mitigation section.

Impact Analysis

Miombo woodland patches will decline in total area by 16 percent and in area per patch by 23 percent during operations. The distance between intact miombo woodland patches will increase by 16 percent. These changes will have a moderate effect on landscape-level biodiversity due to the loss of regional habitat connectivity with miombo woodland throughout the RSA. Impacts are local in extent, medium term in duration, partially reversible and will occur with a high frequency throughout operations. The environmental consequence is low (Table C3.4-8).

After closure, mitigation efforts will reduce landscape-level biodiversity impacts in miombo woodlands to low in magnitude. Although these small effects will persist for the long term, they will be low in environmental consequence (Table C3.4-8).

Table C3.4-8 Residual Impact Classification for Key Question HB-2

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question HB-2:		**What effect will the project have on natural habitats and biodiversity at the landscape level?**					
Intactness and fragmentation of miombo woodlands							
construction and operation	negative	moderate	local	medium-term	no[(a)]	high	low
closure	negative	low	local	long-term	no[(a)]	low	low
Intactness and fragmentation of copper-cobalt steppe-savannah							
construction and operation	negative	moderate to high	local	medium-term	no[(a)]	high	moderate
closure	negative	moderate	local	long-term	no[(a)]	low	moderate
Intactness and fragmentation of gallery forest							
construction and operation	negative	low	local	medium-term	no[(a)]	moderate	low
closure	negative	low	local	long-term	no[(a)]	low	low
Intactness and fragmentation of copper-cobalt rock outcrop							
construction and operation	negative	high	local	medium-term	no[(a)]	high	high
closure	negative	moderate	local	long-term	no[(a)]	low	moderate

[(a)] Partial reversibility with reclamation

Copper-cobalt steppe-savannah patches will be less numerous, of slightly smaller size and will have greater distances between them during the operations phase. The loss of 37 percent of this habitat type, combined with an 11 percent decline in average patch size and 104 percent increase in distances between patches in the LSA all indicate a decline in landscape-level connectivity. Impacts are predicted to be moderate to high during operations. The effects will be local in extent, medium term in duration and partially reversible. A moderate environmental consequence for biodiversity is expected in the operations phase.

After closure, the residual impact on copper-cobalt steppe-savannah will be moderate in magnitude, with the assumption of successful reclamation of much of the habitat type and re-establishment of habitat connectivity through reclaimed areas. The residual impact will be local in extent, long term in duration and

reversible. The overall environmental consequence will be moderate (Table C3.4-8).

The changes to gallery forest during operations will include approximately a three percent decline in area per patch and a one percent increase in mean distances between patches. Although additional impacts could occur due to groundwater drawdown within these habitats, such effects will be fully mitigated by habitat restoration of equivalent areas of gallery forest in other appropriate locations within the concession. Overall, these changes are considered low to moderate during operations. The effect will be local in extent, medium term in duration and partially reversible because reclamation will occur during and immediately after the operations phase. Impacts will be moderate in frequency for the length of the operations phase. The environmental consequence during this phase is low (Table C3.4-8).

At the time of project closure, impacts on gallery forest are expected to be largely mitigated through reclamation and/or environmental compensation. Residual impacts after mitigation will be low in magnitude and therefore low in environmental consequence (Table C3.4-8).

Copper-cobalt rock outcrop habitats will be reduced in total area by approximately 47 percent during the operations phase, and remaining patches will be smaller, on average, with much longer distances between them. This habitat type is naturally infrequent and of small patch size, so these impacts do not necessarily represent a great impact on landscape biodiversity. However, because the ecosystem dynamics are poorly understood and the loss of some localized and unique habitats could occur, this impact is considered high in magnitude. It is local in extent, medium term in duration and is partially reversible. Impacts will occur at a high frequency during the operations phase. The environmental consequence for species-level biodiversity is high (Table C3.4-8).

At closure, reclamation of copper-cobalt rock outcrops and the purposeful construction of such habitats in areas out of the plant/mine facilities, if successful, will reduce the residual impact of the project on species-level biodiversity to moderate in magnitude. The effect will be local in extent, long term in duration, partially reversible, and of low frequency after closure. The environmental consequence will be moderate.

Some of the indirect effects of the TFM project, including in-migration of people, increased land use, and habitat fragmentation will persist long after closure.

Prediction Confidence

The effects of the project on landscape-level biodiversity are moderately well understood. Limitations to the prediction confidence include:

- The complexity of ecological systems (making it difficult to determine the critical patch size of habitat areas, below which habitat integrity is lost).
- Uncertainty with respect to reclamation (can all types of habitat be successfully reclaimed or constructed in the post-closure landscape, or in newly developed natural reserves?).

The prediction confidence for this assessment is moderate.

Monitoring

The monitoring program for biodiversity is as described for key question HB-1.

C3.4.3.6 Key Question HB-3

Key question HB-3 is: How can the project influence natural habitats and biodiversity to have a long-term positive effect?

Assessment Methods

Ways in which the TFM project can initiate long-term, sustainable use or protection of natural habitats and biodiversity are assessed.

Mitigation and Additional Measures

Mitigation and additional measures concerned with long-term sustainability of biodiversity in the LSA and RSA will include:

- Local residents will be engaged to assist with the collection and conservation of rare species and habitats, thereby increasing their knowledge of biodiversity and its importance. For example, local residents will be engaged in the supervised cutting and preparation for transport of rocky outcrop habitat. As described in the BDAP (Section D3.1-II), former artisanal miners will be engaged in this work, but will be under the direct control of TFM environmental staff at all times.
- As part of any environmental education program directed at the public, the project will develop curriculum based on the value of local

biodiversity within the larger context of the DRC, to help encourage environmental awareness among the local population.

- Species-specific mitigation will be carried out as described in Sections C3.1, C3.2 and C.3.3 for flora, fauna and fish and aquatic habitats.
- Education of school children (provision of school materials on biodiversity; tours of sites).
- Select results of field studies (completed for the ESIA and for purposes of monitoring) for flora, fauna and fish and aquatic habitats could be provided to universities in Katanga Province and the Katanga Provincial Environment Department. This will support biodiversity education and will assist in the production of a provincial biodiversity monograph which is part of the Katanga Province plan to meet goals of the international convention on biodiversity (DRC 1999).
- Increase capacity of the DRC by hiring and training DRC nationals for the biodiversity programs, as is planned under the BDAP.
- Improve the University of Lubumbashi herbarium collection by having voucher species cataloged and stored there, and by establishing a seed bank for Cu-Co species, as further described in the BDAP.
- Support graduate students from DRC universities for biodiversity research on process of habitat reconstruction and reclamation.
- In addition to on-site mitigation, the project will consider contributions of resources or reclamation expertise to assist with the initiation of reforestation programs in Katanga province, which is part of the provincial plan to meet goals of the international convention on biodiversity (DRC 1999).

Results

Under baseline conditions, there has been a gradual fragmentation of habitats within the LSA, with a trend toward increasing size of the agricultural mosaic and degraded miombo woodlands, and reductions in areas of gallery forest, miombo woodlands and wetlands. During operations, the TFM project will generate additional impacts on the copper-cobalt flora and fauna within rock outcrop and steppe-savannah habitats. However, mitigation and additional measures that will be put in motion during operations, along with appropriate reclamation of habitats, can benefit biodiversity in the LSA and beyond in the long term.

By working with regional authorities, local residents and non-governmental organizations (NGO), supporting programs for local schools and the University of Lubumbashi on biodiversity, and passing on information obtained through

baseline studies and monitoring, the TFM project can increase awareness of the importance of local biodiversity.

By setting up natural parcels for copper-cobalt flora and fauna, and initially retaining local residents and institutions to assist with the maintenance and protection of these areas, the TFM project can strive to preserve threatened species during the project and help develop a framework for their preservation long after the project is complete.

By working with land users (such as in the agroforestry initiative described in Section C3.1), the potential for long-term incomes from forestry can be enhanced without calling for ongoing impacts to biodiversity and a continuation of long-term trends of habitat fragmentation.

Through potential partnerships with existing protected areas, the TFM project can help to improve the management capacity of such areas for protection and the accommodation of tourism, which has the potential to be a long-term, sustainable income source within the DRC.

Impact Analysis

The positive impacts that can come about for natural habitats and biodiversity, in relation to longer-term sustainability, come from two major initiatives: the establishment of management areas and the use of environmental education and research (Table C3.4-9). By employing a combination of mitigation measures, the chances of having some successes are improved. The sustainability initiatives will be targeted in specific areas initially and may affect relatively few people (mainly those within the LSA or students in Lubumbashi), but can affect many habitat types and species. The effects will be long term in duration. The probability of successful enhancements to natural habitats and biodiversity is considered medium. The overall sustainability consequence for management areas is low. Meanwhile, the magnitude of environmental education and research is considered high, with the entire community affected by various initiatives. The impact will be long term in duration, with a medium probability of success and therefore medium overall consequence (Table C3.4-9).

Table C3.4-9 Residual Impact Classification for Key Question HB-3

Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key question HB-3: How can the project influence natural habitats and biodiversity to have a long-term positive effect?				
Management area				
moderate	a few people	long-term	medium	low
Environmental awareness education				
high	entire community	long-term	medium	moderate

Prediction Confidence

The prediction confidence for any one mitigation measure (effectiveness of a natural area, success of an agroforestry program or success of support to protected areas in establishing a more viable tourism industry) is low, as the success of each measure will depend on many factors outside of the project's control. However, if implemented in combination, the probability of success of some sustainability measures will be increased to medium.

Monitoring

The monitoring program for biodiversity is as described for key question HB-1.

C3.4.4 Cumulative Effects Assessment

Key questions $HB_{(ce)}$-1 and $HB_{(ce)}$-2 relate to the cumulative species and landscape-level impacts of the TFM project and future planned expansions of this project.

Linkage Evaluation

Should the project be expanded from a 115,000 tonnes per year to a 400,000 tonnes per year operation, the physical extent of biodiversity impacts would increase considerably with additional areas being mined and additional areas required for tailings facilities. The linkage is valid for increased impacts on flora, fauna, fish and aquatic resources.

Assessment Methods

Detailed plans for the additional development of the project to expand to 400,000 tonnes per year are not yet available. However, such a development would include additional mines within the Fungurume ore body and an additional

processing plant, as well as more extensive use of the tailings pond north of Fungurume (Section A.17). These effects were reviewed in the context of known baseline conditions for biodiversity. A preliminary model for the footprint of the cumulative case project was overlaid on the mapped vegetation in the RSA. Professional experience in relation to the changes in biodiversity caused by mining, plant sites, waste rock facilities, quarries and linear developments was used to develop an understanding of the potential effect of an expanded project. Principles developed for closure plans and other project goals for long-term mitigation of effects were used to develop an assessment of long-term impacts.

Mitigation

The mitigation presented above for key questions HB-1, HB-2 and HB-3 will be implemented on a greater scale to address the effects of an expanded 400,000 tonnes per year project. At the time of the decision to expand the project, additional assessments of flora, fauna and aquatic habitats would be completed to determine if additional supplementary mitigation is needed.

Results

The effects on natural habitats and biodiversity with a larger, 400,000 tonnes per year project would be greater in magnitude than those predicted for key questions HB-1 and HB-2, but the types of impacts expected would be very similar. Additional losses to all habitat types during project operations would be expected, including additional losses of rare copper-cobalt habitats. When studied on a regional scale, most habitat impacts become smaller in proportion to the larger amount of habitat available. However, the expected habitat losses for the copper-cobalt rock outcrop and copper-cobalt steppe-savannah are expected to be most important because this habitat is rare on a regional basis (Table C3.4-10). In addition, the increase in employment from the larger project will lead to higher in-migration levels and larger indirect impacts on biodiversity due to land use. This will include clearing of forest for agriculture and hunting of fauna for sustenance.

Table C3.4-10 Change in Key Habitat Areas in the Regional Study Area: Cumulative Case

Natural Habitat Type	Regional Project Case Change in Total Area (percent)	Incremental Additional Impact of Cumulative Case	Regional Cumulative Case Change in Total Area (percent)
intact miombo woodland	-4	-1	-5
copper-cobalt steppe-savannah	-31	-8	-39
wetlands	<1	0	-<1
gallery forest	-1	0	-1
copper-cobalt rock outcrop	-84	0	-84

Impact Analysis

For the cumulative development case, impacts will occur across much of the LSA and potentially in additional ore-bearing hills outside of the LSA. Direct impacts on intact miombo woodland and copper-cobalt steppe-savannah will increase (Table C3.4-10) and, because additional indirect impacts of a larger population are expected, the impact magnitudes for each habitat are predicted to increase slightly (Table C3.4-11). The environmental consequence of these effects will be high during operations for the copper-cobalt steppe-savannah and the copper-cobalt rock outcrop. The environmental consequence for miombo woodlands and gallery forest will be moderate during operations. Consequences for all habitat types will be moderate following closure.

Table C3.4-11 Residual Impact Classification for the Cumulative Case

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question $HB_{(ce)}$-1 and $HB_{(ce)}$-2:			**What effect will the project have on biodiversity at the species and landscape level under the cumulative case?**				
Issue: Miombo woodlands							
construction and operation	negative	moderate	regional	medium-term	yes	medium	moderate
closure	negative	low	regional	long-term	yes	low	moderate
Issue: Copper-cobalt steppe-savannah							
construction and operation	negative	high	regional	medium-term	yes	medium	high
closure	negative	low	regional	long-term	yes	low	moderate
Issue: Gallery forest							
construction and operation	negative	moderate	regional	medium-term	yes	medium	moderate
closure	negative	low	regional	long-term	yes	low	moderate
Issue: Copper-cobalt rock outcrop							
construction and operation	negative	high	local	medium-term	yes	medium	high
closure	negative	moderate	local	long-term	yes	low	moderate

As described in Section C3.2, the effects for fauna will likely be high both during operations and after closure, due to indirect impacts such as land clearing and hunting that will continue indefinitely.

Prediction Confidence

Information concerning the effects of a larger, 400,000 tonnes per year project is limited, but a general understanding of the effects of such a project is in place and the assessment results presented in Table C3.4-11 are conservative. The prediction confidence for this assessment is moderate. If this larger project goes ahead, a new environmental assessment with more detailed information about the project will be prepared.

Monitoring

The monitoring program for biodiversity is as described for key question HB-1.

C3.4.5 Conclusions

Four key habitat types (intact miombo woodland, copper-cobalt steppe-savannah, gallery forest, and copper-cobalt rock outcrop) were selected as having the greatest biodiversity values in the LSA. Residual impacts on these habitat types for key questions HB-1 (effects to species-level diversity) and HB-2 (effects to landscape-level natural habitats and biodiversity) are summarized in Table C3.4-12. The greatest impacts will occur during operations, when the largest areas of natural habitats will be cleared, resulting in reduction of areas in which species can live and an increased fragmentation of the remaining patches of habitat. Species-level impacts in the copper-cobalt steppe-savannah and the copper-cobalt rock outcrops are of greatest concern due to the rarity of these habitats and the species within them.

Table C3.4-12 Summary of Impact Predictions for Key Questions HB-1 and HB-2

Habitat	Species-level Impact (Operations)	Species-level Impact (Closure)	Landscape-level Impact (Operations)	Landscape-level Impact (Closure)
intact miombo woodland	low	low	low	low
copper-cobalt steppe-savannah	high	moderate	moderate	moderate
gallery forest	low	low	low	low
copper-cobalt rock outcrop	high	moderate	high	moderate

Following mitigation, environmental compensation, and reclamation, the project will have a low to moderate environmental consequence for all habitat types for both species level and landscape level biodiversity.

Accompanied by potential low or moderate negative impacts due to the loss of specific existing biodiversity and natural habitats, there are possible positive long-term sustainability impacts, relating to improvements in the level of awareness for biodiversity and the protection of biodiversity within specific natural areas, land use plans and managed areas. These sustainability improvements are not certain of success but are rated moderate and positive in overall environmental consequence.

Under the cumulative development case, a project expansion from 115,000 tonnes per year to 400,000 tonnes per year could considerably increase the extent of impacts on natural habitats and biodiversity. The environmental consequence of these effects will be high during operations for the copper-cobalt steppe-savannah and the copper-cobalt rock outcrop. The environmental consequence for miombo woodlands and gallery forest will be moderate during operations. Consequences for all habitat types will be moderate following closure. These ratings are conservative, because the uncertainty of predictions under the cumulative development case is higher than the uncertainty for the project alone.

C3.5 PROTECTED AREAS

C3.5.1 Introduction

This section presents the environmental assessment for the effects of the project on protected areas as required by the project's terms of reference (Appendix E8). The information presented includes details on:

- Potential issues regarding changes to protected areas.
- Project activities that may affect protected areas.
- Mitigations incorporated in the project design for these impacts.
- Impact assessment approach and results for key protected area issues.
- Sustainability assessment approach and results for protected area issues.
- Identified measures relating to protected areas to promote long term economic and social sustainability in the project area.

This section is organized as follows:

- Section C3.5.2 describes the study area.
- Section C3.5.3 discusses the impact assessment approach.
- Section C3.5.4 provides the cumulative effects assessment.
- Section C3.5.5 presents the conclusions of the impact assessment.

Baseline information concerning protected areas has been provided in Section B3.5.

A glossary of terms and acronyms used is provided at the back of this volume.

C3.5.2 Study Areas

The study areas for this impact assessment are the same as those for the protected areas baseline. They are described in Section C1.

A Regional Study Area (RSA) for parts of the Democratic Republic of the Congo (DRC) within 100 kilometers of the Tenke Fungurume Mining (TFM) project is assessed in order to provide a basis to evaluate potential indirect impacts of the project (Figure C1.7-1). Indirect effects include those related to in-migration to the area and a rise in the standard of living in the region. Both of these could result in increased visitation to parks and reserves. One hundred kilometers is considered appropriate to assess all potential indirect impacts, as this is a distance

within which people are considered to have the potential to travel from their homes near the project to a protected area. Due to relatively poor access conditions into the nearby protected areas, impacts at distances over 100 kilometers are considered unlikely.

A Local Study Area (LSA) including impact areas for the mine, plant, personnel camps, roads, the limestone quarry and other infrastructure, plus a 500-meter buffer (equivalent to the terrestrial LSA) (Figure C1.6-1) is assessed to provide a basis to evaluate potential direct impacts of the project.

C3.5.3 Impact Assessment

C3.5.3.1 Issue Scoping

Key issues of potential relevance to protected areas are:

- 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 air quality, water quality or water quantity.
- Indirect impacts in an area due to induced development, and subsequent changes in land use or changes in tourism.
- Enhanced protection or management of protected lands due to financial support from the project or project employees.

Issues pertaining to protected areas noted during the public consultation process (Section A6.2) include:

- General issues relating to the protection of the environment (such as improvements to the natural environment and soil stability).
- Potential economic benefits to communities that could result from re-forestation programs (such as direct employment or the development of a silviculture industry).

Such issues were not always specific to protected areas.

A suggestion was made during the consultation process for the establishment of a conservation area in the concession for the protection of plants and wildlife.

C3.5.3.2 Key Questions and Indicators

The key questions for protected areas are listed in Table C3.5-1.

Table C3.5-1 Key Questions for Protected Areas

Impact Assessment
PA-1 What effects, direct and indirect, will the project have on protected areas?
Sustainability Assessment
PA-2 How can the project influence protected areas to have a long term positive effect?

Key indicators assessed are the percentage of protected areas physically affected by the project, and the approximate quantity in numbers of people using protected areas. Indicators relating indirectly to protected areas include the following Global Reporting Initiative (GRI) sustainability indicators (GRI 2005b):

- EN25 Impacts of activities and operations on protected and sensitive areas.
- EN26 Changes to natural habitats resulting from activities and operations and percentage of habitat protected or restored.
- EN27 Objectives, programs and targets for protecting and restoring native ecosystems and species in degraded areas.

C3.5.3.3 Assessment Criteria

Assessment criteria for protected areas are presented in Table C3.5-2. The screening system for sustainability consequence is provided in Section A5.

C3.5.3.4 Key Question PA-1

Key question PA-1 is: What effects, direct and indirect, will the project have on protected areas?

Table C3.5-2 Impact Assessment Criteria for Protected Areas

Direction[a]	Magnitude[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
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 on 10% or less of a protected area and/or moderate indirect impacts **high:** physical effects on 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 20 years **long term:** <20 years	reversible or irreversible	**low:** occurs once or rarely **medium:** occurs intermittently **high:** occurs continuously

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

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

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

(d) Duration: length of time over which the environmental effects occurs. Considers a two-year construction period and a 20-year operations period.

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

(f) Frequency: how often the impact occurs.

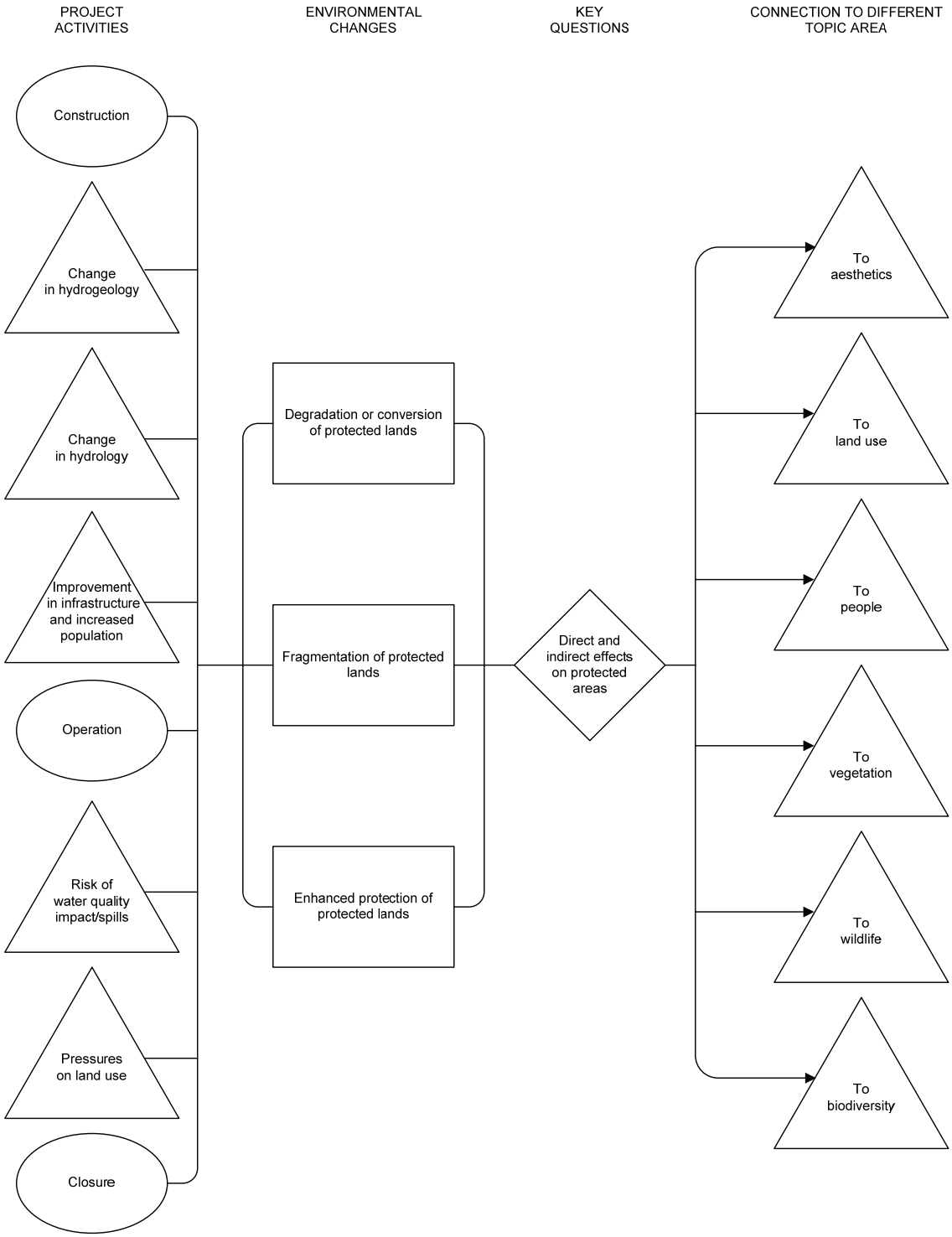
Linkage Evaluation

A diagram showing the potential project activities impacting protected areas is provided (Figure C3.5-1). Potential linkages occur in all phases of the project (construction, operation and closure) and include possible changes in hydrogeology, hydrology and water quality as well as changes in socio-economics and land use. These changes, combined with direct impacts of the project, could degrade or fragment protected lands, alter water flow and quality on protected lands, and could alter the use of protected areas.

The nearest protected area to the project is 75 kilometers away. Therefore, direct effects on protected areas (habitat alteration or fragmentation) will not occur. The Mofia River is tributary to the Dikuluwe River system that flows into Kundelungu National Park about 100 kilometers downstream. Linkages for effects of change in hydrology, hydrogeology, water quality and direct degradation, conversion or fragmentation of protected lands are all invalid.

There are five protected areas located within the RSA: Upemba National Park, Kundelungu National Park, Lubudi-Sampra Hunting Reserve, Tshangalele Hunting Reserve and Lufira Biosphere Reserve (Figure C1.7-1). Therefore, indirect effects on protected areas due to changes in population, infrastructure or air quality may occur. This linkage is valid.

Figure C3.5-1 Protected Areas Linkage Diagram



Assessment Methods

Data relating to protected areas were collected from recent literature, published maps, reliable websites and communication with conservation organizations. Environmental and social impact assessment (ESIA) sections for socio-economics and air quality were reviewed to evaluate potential indirect effects of population change and air quality on protected areas within the RSA.

Mitigation

The following mitigation measures will be used to minimize impacts on protected areas:

- Air emissions will be limited through the use of appropriate technology and emission controls as described in Section C2.8. Although mainly of concern for local air quality effects, these efforts will also serve to keep any effects on protected areas to a negligible level.
- Worker education on valued biodiversity in the Upemba and Kundelungu National Parks and the Lufira Biosphere Reserve will be provided by the project in order to foster understanding and care for such areas, both among local and expatriate employees, perhaps contributing to self-sufficiency of protected areas as ecotourism destinations.
- Specific mitigation for reducing risks posed by transport of goods through protected areas that occur between the project and potential port sites (Dar Es Salaam, Durban, Richards Bay and Walvis Bay) is described in Section C2.6. This mitigation is planned in addition to standard best practices for safe transport of goods described in Section C2.13. Because existing transport corridors are being used, no additional development of these corridors is occurring, and these types of transport activities are already permitted.

Impact Analysis

Air Quality

Air quality impacts can have an effect on environmental conditions in protected areas. However, the greatest air quality effects are generally limited to within 10 kilometers of emissions sources (air quality assessment, Section C2.8). The air quality may change slightly over protected areas under some meteorological conditions, but this change is expected to be negligible (Table C3.5-3).

Table C3.5-3 Residual Impact Classification for Key Question PA-1

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Key question PA-1: What effects, direct and indirect, will the project have on protected areas?						
Issue: Air quality changes						
negative	negligible	regional	medium term	yes	continuous	Negligible
Issue: Indirect impacts of social / population changes (land use modification)						
negative	negligible	regional	medium term	yes	low	Negligible
Issue: Indirect impacts of social / population changes (tourism)						
positive	negligible	regional	medium term	yes	medium	Negligible

Land Use Modification

The population of the LSA is expected to increase as a result of in-migration and improved health care (Section C4.1). The indirect effects of this increase in population to protected areas around the project are predicted to be negligible. In general, people will not travel from the project areas to the protected areas in the RSA due to distance, lack of disposable income for discretionary, recreational travel, lack of private and public transportation and challenges associated with roads. People migrating from other parts of the DRC intending to find employment with the project are likely to move very close to the project and not engage in new land use activities within the protected areas. Indirect impacts due to land use modification by migrants into the area are expected to be negligible in magnitude, regional in extent, medium term in duration, reversible and occur on a continuous basis. The environmental consequence is negligible (Table C3.5-3).

Tourism

The project may marginally increase visitation to protected areas, mainly by expatriate workers, due to a combination of increasing numbers of workers in the area and improving some of the local road infrastructure. Indirect impacts due to tourism are considered positive because they inject money into the protected areas system, allowing for improved management with a limited physical impact. Poor road conditions and lack of visitor facilities in nearby protected areas will limit this impact. The magnitude of this impact is predicted to be negligible, regional in extent, medium term in duration, reversible and occur on a continuous basis. The environmental consequence is considered to be negligible (Table C3.5-3).

Prediction Confidence

The prediction confidence for this assessment is high. Minor uncertainties are associated with the extent of the indirect impacts caused by migrants, workers and visitors to the project who visit or use resources from the protected areas in the RSA.

C3.5.3.5 Key Question PA-2

Key question PA-2 is: How can the project influence protected areas to have a long term positive effect?

Assessment Methods

In general, assessment methods used for PA-2 were the same as PA-1. The possible long term benefits of the project for sustainability of the cultural and natural resources of protected areas were assessed, taking into consideration the location and current condition of protected areas in the RSA.

Mitigation and Additional Measures

Depending on the decision of stakeholders, including local people, non-governmental organizations (NGOs) and the government of the DRC, an initiative to support the management of one or more existing protected areas in the region may be considered. One national park in the vicinity would be selected, and a capacity-building program for the management of this area would be developed.

As discussed for key question PA-1 the project can eventually provide worker education on valued biodiversity within the DRC for protected areas within driving distance in order to foster understanding and care for such areas (once private cars became more prevalent in the concession). Such education could target both local and expatriate employees, and contribute to self-sufficiency of protected areas as ecotourism destinations. As described in Section C3.5.3.2, helping to protect native ecosystems is a good indicator for the success of sustainability efforts. In the long term, contributing to develop a tourism base in regional protected areas can help establish an income stream to assist with managing of protected areas such as Upemba and Kundelungu National Parks.

The copper-cobalt flora of the region includes many rare or threatened plants and pro-active conservation initiatives for this flora/habitat is another way in which the project can have a positive long term impact on sustainability through the use of protected areas. The flora assessment (Section C3.1) discusses the protection of copper-cobalt flora communities and the initiatives TFM will establish for the conservation of those habitats (Section B3.1)

TFM will provide information gathered concerning the flora, fauna and unique species in the LSA to interested local residents and non-governmental organizations (NGOs). TFM will further work with the Lubumbashi University and both local and national-level NGOs on plans to develop research striving to protect the rare copper-cobalt habitats. By building an understanding and acceptance of the value of these habitats within the local community, the potential for their long-term protection will be enhanced.

Impact Analysis

The positive impacts that can come about for protected areas, in relation to longer-term sustainability will depend on the relative priority of these issues and the resources that can be spared to address them. Key indicators of positive effects will be the protection or restoration of a high percentage of habitats that are impacted, and the establishment of specific objectives, programs and targets for protecting and restoring native ecosystems and species in degraded areas. In the context of the region as a whole, the magnitude of such efforts is predicted to be low to medium. The positive effects of preserving some copper-cobalt natural areas will reach a few people locally, but could be considered of international importance due to the rarity of the species being protected. The positive effects of contribution to the regional parks system, in terms such as building local capacities and worker's education, could reach many people (about half the regional community). Both effects would be long term in duration. Efforts to conserve the copper-cobalt flora have a medium probability of success, while the more ambitious goal of assisting the regional parks system has a low to medium probability of success depending on the level of resources that can be allocated to this, and on other external factors. The sustainability consequence is therefore low to medium in both cases (Table C3.5-4).

Table C3.5-4 Residual Impact Classification for Key Question PA-2

Protected Areas of Interest	Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key question PA-2:	**How can the project influence protected areas to have a long term positive effect?**				
regional parks	low to medium	to half the community	long term	low to medium	low to medium
local protected areas for copper-cobalt habitats	low to medium	to a few people	long term	medium	low to medium

Prediction Confidence

The positive impacts that can come about for protected areas, in relation to longer term sustainability, will depend on the evolving socio-economic conditions in the RSA and the relative priority of such efforts undertaken for the proponent. At present, the prediction confidence in relation to such measures is low to moderate.

C3.5.3.6 Monitoring

Section D3.1.12 describes proposed monitoring for future conservation areas. No other monitoring is proposed specifically for protected areas.

C3.5.4 Cumulative Effects Assessment

Linkage Evaluation

Should the project be expanded from a 115,000 tonnes per year to a 400,000 tonnes per year operation, the physical impact of the project would still be distant from existing protected areas, so no direct impacts would occur. This linkage would remain invalid.

Under the cumulative development case, employment opportunities and in-migration would increase, resulting in greater indirect effects. The linkage for indirect cumulative effects is valid.

Assessment Methods

The assessment of potential cumulative effects was performed based on this, using professional judgment to estimate likely levels of indirect effects.

Mitigation

No mitigation beyond that proposed for Key questions PA-1 and PA-2 is proposed.

Impact Analysis

Detailed plans for the additional development of the project to expand to 400,000 tonnes per year are not yet available. However, such a development would sustain higher levels of employment for a longer period of time, resulting in additional in-migration of people within the RSA, additional employment of both local and expatriate workers and an eventual rise in the standard of living, with a concomitant rise in personal vehicle ownership and a possible improvement in road infrastructure.

The effects on protected areas with a larger, 400,000 tonnes per year project would be greater in magnitude than those predicted for key question PA-1, but the types of impacts that are expected would be very similar. Air quality effects are expected to remain negligible for protected areas (Table C3.5-5). The protected areas are well beyond the distances at which air quality impacts could be experienced. Additional migration of people into the RSA is also unlikely to extend close to the few reserves and negligible impacts should be experienced as a result of this. Population-related impacts are predicted to be negligible, regional in extent, long term in duration, reversible and occurring with a medium frequency. The environmental consequence of these effects is predicted to be negligible and positive for tourism (non-extractive) activities because these activities, correctly managed, fit within the goals of the protected areas and can benefit the protection of these areas. The environmental consequence will be negligible and negative for land use (extractive) activities because most forms of extractive land use will hinder the sustainability of protected areas (Table C3.5-5).

Table C3.5-5 Cumulative Residual Impact Classification on Protected Areas

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Environmental Consequence
Issue: Air quality changes						
negative	negligible	regional	medium term	reversible	continuous	negligible
Issue: Indirect impacts of social / population changes (land use modification)						
negative	negligible	regional	medium term	reversible	medium	negligible
Issue: Indirect impacts of social / population changes (tourism)						
positive	negligible	regional	medium term	reversible	medium	negligible

Prediction Confidence

Due to uncertainty regarding the indirect impacts of a larger project, and uncertainty regarding the nature of some mitigation measures, prediction confidence is low to moderate.

C3.5.5 Conclusions

Residual impacts to protected areas have been summarized above in Tables C3.5-3, C3.5-4 and C3.5-5.

The project will have no direct impacts on protected areas, as no protected areas are in the LSA. Long-distance indirect impacts on five protected areas that lie within 100 kilometers of the project (Upemba National Park, Kundelungu

National Park, Lubudi-Sampra Hunting Reserve, Tshangalele Hunting Reserve and Lufira Biosphere Reserve) are expected to be negligible. Air quality effects on these areas are predicted to be negligible, due to the distance away from the project. Negative effects due to new land use in protected areas following the in-migration of people due to the project are also expected to be negligible. Increased tourism as a result of the greater number of people with income available for recreational purposes may have a slight beneficial impact but the environmental consequence of this is also expected to be negligible.

Population-related effects will rise under the cumulative development case, but these effects are still predicted to be negligible for protected areas 75 kilometers or more away. This is predicted for both negative effects of new land use and positive effects due to direct financial inputs into ecotourism activities at the protected areas.

Long term efforts to support the achievement of sustainability indicators may include education about the importance of the cultural and biological heritage of nearby protected areas, direct support for the management of existing protected areas or cooperative efforts with NGOs or government agencies to establish natural reserves for the copper-cobalt flora and fauna within the LSA.

C4.1 SOCIO-ECONOMIC IMPACT ASSESSMENT

C4.1.1 Introduction

This section presents the predicted impacts of the Tenke Fungurume Mining (TFM) project on social and economic environments. The following methods have been used to predict effects from the TFM project, to assess their significance, and to design appropriate methods for avoidance or mitigation of unavoidable impacts:

- Observed impacts of other mining or industrial projects recently implemented in Africa have been used as examples, insofar as they are comparable in magnitude and scope and are situated in similar social and economic conditions (e.g., other large mines in the Democratic Republic of the Congo [DRC] and particularly in Katanga province, Chad oil project and the Chad to Cameroon pipeline, and gold mines in Mali, Guinea and Ghana).
- Consideration was taken of the singularities of the local situation, such as the current sources of livelihoods, the present condition of the local economy, the social and political/administrative organization, and the status of civil society.
- Use has been made of available best practice documentation in relation with social impact assessment, particularly that issued by the World Bank Group, commonly referred to as Equator Principles.

This section is organized as follows:

- Section C4.1.2 describes the study areas.
- Section C4.1.3 presents the anticipated impacts of the project.
- Section C4.1.4 provides the cumulative effects.
- Section C4.1.5 provides the conclusions of the assessment.

The general methodology of impact description and assessment is described in Section A5 of the environmental and social impact assessment (ESIA). Impacts for socio-economics are described in terms of extent, duration, intensity, and probability, and assessed in terms of direction (positive or negative) and significance (low, medium, high).

A detailed socio-economic baseline is presented in Section B4.1.

An assessment of the macro-economic effects of the project is provided in Appendix C4.1-I.

A glossary of terms and acronyms used is provided at the back of this volume.

C4.1.2 Study Areas

Socio-economic study areas include consideration of potential effects at the national, regional and local levels. Regional Study Areas (RSAs) for the socio-economic assessment include the nation (for macro-economic impacts at the level of the country), the provinces of Katanga and the Kolwezi District (Figure C1.8-1). The socio-economic baseline Local Study Area (LSA) includes the footprint of the mine and its area of direct and indirect influence, including the adjoining towns that will be most affected (e.g., Tenke and smaller villages) (Figure C1.8-2). The LSA falls within the jurisdiction of the Kolwezi District.

In addition to the urban areas of Tenke and Fungurume, at least 41 villages and hamlets fall within the LSA. The LSA includes the following five regions:

- Urban Tenke and Fungurume.
- Suburban villages of Mpala and Bloc Mitumba.
- Villages along the national highway between Fungurume and Tenke.
- Villages directly between the railroad and the direct concession area: Mwela Mpande Gare, Kwatebala Gare, villages between Kasanga and Mulumbu, and villages along the Tenke to Salabwe Road.
- Northern villages around the limestone quarry site, the airstrip and Lukotola.

C4.1.3 Impact Assessment

Details of proposed mitigation measures are found in the Social Action Plans (Section D4). A summary of additional non-mitigation-driven social investments is provided in the Community Development Plan (Section D4.4).

C4.1.3.1 Standards and Guidelines

Standards and guidelines used by international finance institutions with relevance to social and economic impacts and their avoidance or mitigation include the following:

- The International Finance Corporation (IFC) Policy on Environmental and Social Sustainability.

- The IFC's eight Performance Standards, and the related guidance notes.
- The World Bank Group policy on Public Consultation and Disclosure (included in OD 4.01 and its annexes).
- The IFC handbook on Involuntary Resettlement.

Documentation describing these standards can be found at www.ifc.org.

C4.1.3.2 Identification of Potential Socio-economic Impacts – Summary Tables

Tables C4.1-1 and C4.1-2 present the potential socio-economic impacts likely to be experienced during the construction and operation phases of the project. Information is presented on each impact in terms of criteria described in the Equator Principles and IFC guidance documents, as summarized below:

- Impact direction, specifically whether it will produce a positive or adverse (negative) effect.
- The anticipated geographic extent, specifically whether local, regional or national effects are expected.
- The impact intensity, in terms of whether high, medium or low-level effects are expected.
- The probability of the expected impact in terms of whether it is 'certain' to happen or will 'probably' happen.
- The impact duration in terms of whether short, medium or long term.
- The significance of the impact in terms of whether or not the effects have low, medium or high consequences; both before and after mitigation measures are applied.

C4.1.3.3 Description of Potential Socio-economic Impacts – Construction

The following narrative expands on the summary impact descriptions provided in the preceding tables.

Land Use

Three types of land use related impacts are identified, including impacts to livelihoods and residences.

Table C4.1-1 Anticipated Impacts from the Construction Phase of the TFM Project

Topics	Impact Number	Impact Description	Direction	Extent	Intensity	Probability	Duration	Significance without Mitigation	Significance with Mitigation
land use / agricultural land	C1	loss of agricultural land due to occupation by the project, potentially resulting in loss of income streams and means of livelihood (economic displacement), pressure on land, and land-related conflict	negative	local	high	certain	long-term	high	medium
land use / agricultural land	C2	severed access to agricultural land remaining itself unaffected	negative	local	high	certain	long-term	medium	low
land use / physical displacement	C3	physical displacement of households residing within the project footprint or within the boundary of safety or environmental buffer zones	negative	local	high	certain	long-term	high	high
demography / workforce	C4	strain on local housing, infrastructure and services, potentially detrimental to locals, resulting from a potential in-flux of job-seekers and workers from outside the area	negative	local	high	probable	short-term	high	medium
demography / workforce	C5	development of spontaneous settlements (shantytowns) near the project facilities, or in the towns of Fungurume and Tenke, in relation with the influx of job-seekers and other in-migrants	negative	local	high	probable	short-term	high	low
demography / workforce	C6	risks of disruption and cultural conflict with locals resulting from a potential influx of job-seekers and workers from outside the area	negative	local	medium	probable	short-term	medium	low
demography / workforce	C7	influx of predominantly male job-seekers and workers, potentially living alone, with associated risks that sexually transmitted diseases, including HIV/AIDS, may spread	negative	local	high	certain	long-term	high	medium
demography / workforce	C8	training required for workforce may result in long-term improvement of local population employability	positive	regional	medium	probable	long-term	-	-
economy	C9	inflation caused by the influx of well-paid construction workers, potentially detrimental to the poorest in the community	negative	regional	high	probable	short-term	medium	low

Table C4.1-1 Anticipated Impacts from the Construction Phase of the TFM Project (continued)

Topics	Impact Number	Impact Description	Direction	Extent	Intensity	Probability	Duration	Significance without Mitigation	Significance with Mitigation
economy	C10	loss of local income to diggers, buyers and the local economy in general caused by the interruption of unauthorized artisanal mining	negative	local	high	certain	short-term	medium	medium
economy	C11	improvement in local household income due to employment at the project during construction	positive	regional	high	certain	short-term	-	-
economy	C12	local and regional economic “boom” during construction	positive	regional	high	certain	short-term	-	-
economy	C13	local and regional economic depression at the end of construction	negative	regional	high	certain	short-term	high	medium
labor	C14	labor conflicts at the end of construction when construction workers’ work contracts are terminated	negative	local	high	probable	short-term	high	low
labor	C15	spill-over of labor conflicts at the project to the neighboring communities	negative	local	high	positive	regional	high	low
infrastructure	C16	long-lasting improvements to local infrastructure due to infrastructure upgrades required for construction	positive	regional	medium	probable	long-term	-	-
infrastructure	C17	local road infrastructure could be negatively affected by increased heavy-load traffic	negative	local	low	probable	long-term	medium	low
community safety	C18	safety hazards to neighboring communities in relation with increased traffic along the roads used by project traffic	negative	local	medium	probable	short-term	high	low
community safety	C19	safety hazards to neighboring communities in relation with construction activities at construction sites	negative	local	medium	probable	short-term	high	low
social fabric	C20	increase in crime and other social ailments (alcoholism, prostitution, drug use) caused by an influx of outsiders perceived as well paid and an influx of job-seekers remaining unemployed	negative	local	medium	probable	short-term	medium	low
social fabric	C21	social disruption caused by compensation (social jealousy, fraudulent activities aiming at maximizing compensation) and employment – gap between “haves” and “have-nots”	negative	local	medium	probable	short-term	medium	low

Table C4.1-2 Anticipated Impacts from the Operation Phase of the TFM Project

Topics	Impact Number	Impact Description	Status	Extent	Intensity	Probability	Duration	Significance Without Mitigation	Significance With Mitigation
land use / agricultural land	OP1	severed access to agricultural land, which itself remains unaffected	negative	local	high	certain	long-term	medium	low
economy	OP2	increase in fiscal resources available to local and non-local levels of government	positive	local, regional, national	high	certain	long-term	-	-
infrastructure	OP3	local road infrastructure could be negatively affected by increased heavy-load traffic	negative	local	low	probable	long-term	medium	low
community safety	OP4	safety hazards to neighboring communities related to increased traffic	negative	local	medium	probable	long-term	high	low

Impact C1: Loss of Agricultural Land

The project site is located mainly within the territory of the villages of Mulumbu, Kiboko and Amoni. As any rural land in the DRC, these lands are deemed to be state-owned. In addition, the Amended and Restated Mining Convention (ARMC) confers surface rights to the Concession Holder. However, this land is traditionally used by both local and transient farmers, who exert locally recognized rights of occupation and usufruct, conferred to them by the rightful authority (the local "Chef de Terre" or village chief).

Unless adequately compensated, loss of this land due to occupation by the project may result in loss of income streams and means of livelihood (economic displacement) for the affected farmers. In addition, this impact could result in increased pressure on other, remaining lands, and entail land-related conflicts between locals and the project, or between locals amongst themselves. This impact, and proposed mitigation measures thereof, is addressed in detail in Section D4.3 and Appendix D4.3-I, which present the TFM project resettlement action plan (RAP).

Impact C2: Severed Access to Unaffected Agricultural Land

Agricultural land, albeit unaffected directly, may become difficult to access for its users as a result of the project footprint. This could apply mainly around Mulumbu village near the plant site. This impact is also addressed in the RAP.

Impact C3: Physical Displacement

Where permanent residences fall within the project footprint, residents will be physically displaced. This impact will apply to the villages of Mulumbu in its entirety (approximately 1,200 individuals would be physically displaced), as well as the villages of Amoni (approximately 260 individuals) and Kiboko (approximately 120 individuals).

This impact, and proposed mitigation measures thereof, is also addressed in detail in the project RAP.

Demography / Workforce

There are five impacts to the local demographic structure, primarily related to the anticipated influx of new population from outside the LSA.

Impact C4: Influx of Job-Seekers and Workers, Strains on Local Infrastructure

This negative impact is typically observed on similar projects in Africa, when a large workforce is brought in from outside the project area to participate in the

construction of the project. The peak in workforce is expected to reach about 3,100 individuals (2,000 for construction and 1,100 for operation), all of whom cannot be hired locally. In addition to the workers themselves and their families or dependents, it is to be expected that a large number of job-seekers and other people may come to the project area in search of work and other related opportunities (petty trade, commercial sex, etc.), as unemployment is high in the Katanga province and the DRC as a whole, and construction jobs are usually expected to be better paid than others. Experience of other projects in Central Africa clearly indicates that this is a potentially serious impact.

Unless adequate mitigation measures are in place, this influx of workers and job-seekers might result in undesirable pressure on existing housing, and such marginal infrastructure as already exists in the TFM area.

Impact C5: Development of Spontaneous Settlements

This impact is closely related with Impact C4 described above. It is typically observed on similar projects that in-migrants tend to have little or no financial resources when they arrive, and therefore settle illegally in precarious housing either near the project facilities in the expectation that this will make it easier for them to seize any work opportunity that may arise, or in town. In the case of the TFM project, unless the situation is otherwise managed through mitigation measures it could be envisioned that people would settle near the construction site main gate near the present location of the village of Mulumbu, or in the surroundings of the towns of Tenke and Fungurume. It is also observed that when unauthorized artisanal mining was active in the area, such settlements did appear near the village of Mulumbu.

Unless adequately mitigated, this impact in turn entails a number of undesirable consequences:

- Sanitation conditions in such settlements are usually disastrous, which may entail morbidity risks not only for the residents themselves but also for the project workforce and the community at large.
- Focusing on short-term gains, local chiefs tend to charge small fees to allow people to settle, which makes them unwilling to solve the problem when negative impacts start to appear.
- Informal settlers who do not get a job or other economic opportunity secure a minimal livelihood by engaging in agriculture, which if unmanaged causes pressure on agricultural land and has potential for land conflicts with locals.

Mitigation measures for these impacts are discussed in subsequent sections.

Impact C6: Risks of Disruption and Cultural Conflict

Another potential negative impact of the influx of workers and job-seekers is potential disruption to local residents, particularly resulting from the settlement of new populations with different cultural values or religions. As mentioned in the baseline study, the LSA is a melting pot of recently settled people, which is in itself a positive factor in relation with this potential impact. History of recent conflicts in the DRC indicates, however, that this potential impact certainly needs to be managed with appropriate attention.

Impact C7: Influx of Job-Seekers and Workers and Associated Sexually Transmitted Diseases and HIV/AIDS Risks

This potential negative impact is also typical of similar projects that need a significant workforce to be brought in from outside the project area. Workers living alone and with higher incomes than the general population represent a significant risk of increase in sexually transmitted diseases (STDs) (including human immunodeficiency virus/acquired immune deficiency [HIV/AIDS]), as they may resort to commercial sex workers and cause an increase in adultery in the local community. The baseline study clearly indicates that while there is overall a good awareness of HIV/AIDS, means of prevention (condoms) are not widely used. It also indicates that when artisanal mining was active, people reported an increase in risky behaviors.

In addition, because of the nature and conditions of work in the long-distance transport industry (often involving poor working conditions and long periods away from home), transport workers are considered to be at a much higher risk of HIV infection. As acknowledged in the *ILO Code of Practice on HIV/AIDS and the World of Work, Guidelines for the Transport Sector (2005),* and the *SADC Transport Sector Strategic HIV/AIDS Plan (2001)*, HIV/AIDS prevalence is higher among transport workers, particularly long-distance drivers on major corridors, than in the general population in several African countries. This has the potential to compound the potentially negative impacts associated with HIV/AIDS and the workforce.

Impact C8: Training and Improvement of Employability

A positive impact of local recruitment of a significant part of the workforce for construction is that the employability of those who are hired will improve. Temporarily hired local workers will obtain on-the-job training in aspects such as safety and other technical topics, which will enhance their capacity to obtain better jobs later.

Economy

There are five impacts that are predominantly economic in their effect that originate with the increase in local economic circulation caused by the project, as well as reduced circulation caused by the loss of artisanal mining and at the end of the TFM mine construction period.

Impact C9: Inflation Caused by the Influx of Well-Paid Construction Workers

A potential adverse effect of the influx of workers with higher purchasing power than the local population is a rise in prices of housing, staples, and other basic goods and services. This is typically observed on similar projects in Africa, and may apply particularly to relatively small markets like Fungurume and Tenke. This impact is of course detrimental to the local population, particularly to the poorest in the community. Baseline data have been collected, and a routine already established for ongoing monitoring of prices based on purchase of a shopping basket of staple goods in the markets of Fungurume and Tenke, and using Likasi as regional control. These data will be used for long-term monitoring of trends in local prices, and for the mitigation of impacts to the poorest members of the local community.

Impact C10: Interruption of Artisanal Mining and Related Losses of Income

This impact has already occurred with the termination in late 2005 of the unauthorized, artisanal mining activities that were booming in 2004 and 2005 in the TFM concession area. The baseline survey indicates that people in the several communities where heterogenite digging was active experienced a loss in income when the activity was interrupted. The influx of diggers caused a boom in trading activities, which was particularly visible in the towns of Fungurume and Tenke. Animosity between the diggers and TFM was also commonly observed during the time of highest conflict between Mines Police and diggers over the 2004-2005 periods, but hostility has all but disappeared with the cessation of artisanal mining in the concession. Local residents have attributed this improvement to their hopes that something better will replace the unauthorized digging.

Impact C11: Project Employment and Related Improvements in Income

Of the total project workforce, a number of workers will be hired locally, both from the two towns of Fungurume and Tenke, and from the local villages in the LSA. Local residents hired for the project will receive a salary, which is expected to benefit both the households themselves, and the local economy through the increase in purchasing power and a shift towards monetary exchanges (presently based to a large extent on barter).

The number of direct project hires is predicted to be about 2,000 construction workers during the construction phase and 1,100 operation workers during the operation phase. There have been numerous attempts on similar projects in Africa and elsewhere at estimating the number of indirect jobs created (or sustained) in addition to each direct formal project job. Economic analysis performed in support of the socio-economic impact assessment (see Appendix C4.1-1, Macro-Economic Assessment) provides estimates of this "multiplying factor" on the order of four indirect jobs for each formal direct project job (Appendix C4.1-1). In this case, given the likely structure of the supply chain, a significant number of these jobs will be created (or sustained) outside of the LSA, such as in Lubumbashi, South Africa or the USA. In the context of the DRC, it is estimated that a total of 8,000 indirect construction phase jobs and 4,000 indirect operation phase jobs will be created in the DRC in addition to the direct jobs described above. This does not include jobs in the informal economy.

Impact C12: Local Economic "Boom" During Construction

This positive impact results from the influx of workers with higher purchasing power, local recruitment, and local procurement. The positive effects of this boom can be enhanced through a range of economic development measures currently being planned under the project CDP (Section D4.4), and which will be discussed among TFM its stakeholders, including local government, non-governmental organizations (NGOs) and representatives of the local communities.

Impact C13: Local Economic Depression at the End of Construction

This negative impact is a direct consequence of construction completion, and the termination of work and procurement contracts that result. Construction completion and subsequent demobilization of workers and local suppliers needs to be carefully planned well in advance. In addition to specific mitigation measures of this impact, the CDP will be also intended as a tool to prepare the communities for the aftermath of the end of construction.

Labor

There are two impacts that are primarily labor-oriented.

Impact C14: Labor Conflicts at the End of Construction

Even if pro-actively managed during the construction phase, experience in Central Africa indicates that labor conflicts are difficult to avoid at the end of construction, when numerous work contracts are terminated. The main reasons for these labor conflicts usually include the following:

- Poor understanding by the workers of the terms and conditions of their work contracts, and/or of the provisions of the Labor Code.
- Poor human relation policies and implementation thereof, with failure of the employer to pro-actively explain termination provisions.
- Non-compliance with Labor Code or work contract provisions by employers (including contractors and the whole chain of sub-contractors) and failure to provide legally agreed packages or to provide sufficient notice of termination.
- Poor workers' organization, with absence of Unions, or failure of Unions to fulfill their information, negotiation and conflict resolution missions.
- Manipulation of workers by dishonest individuals seeking to cause conflict in the anticipation that they may take individual benefit from the situation and its eventual resolution.

Work conflict may result in legal action against the companies forming part of the project, but also in strike and other undesirable consequences, including local civil unrest (see Impact C15 below). It has the potential to be most damaging to community relations, notwithstanding efforts made in other areas to engage and establish a proper long-term relationship with neighboring communities, such as community development initiatives. No community relation policy can be successful if labor relations are not appropriately managed.

Impact C15: Spill-Over of Labor Conflicts to the Neighboring Communities

Where labor conflicts are not avoided, or not managed appropriately if they do occur, the issue may spill-over to the neighboring communities. Workers are also largely community members as well, and their family members may want to get involved in the labor conflict. Local politicians and chiefs may also try to get involved with agendas that are not necessarily directly related with the conflict at stake.

Infrastructure

One positive and one negative impact are anticipated on local and regional infrastructure.

Impact C16: Improvements to Local Infrastructure

Project construction will require infrastructure upgrades in the power, road, communications and water supply sectors, which will remain after the end of construction and will be beneficial to the overall community in the concession area and beyond.

Impact C17: Impacts of Heavy Traffic on Local Road Infrastructure

A typical result of similar large-scale construction projects is negative effects on roads generated by heavy loads hauled to the project site. A baseline survey of the pre-construction condition of roads likely to be intensively used for construction purposes is a common approach used to gauge appropriate mitigation for this impact, as well as close ongoing consultation with relevant authorities at regional and national levels, to include regional highways outside of the concession area. In the case of the TFM project, the concession area and regional road networks alike are in a very poor state, and considerable stakeholder concern has already been voiced through the public consultation process regarding expectations for investment in public road maintenance, with particular regard to the national highway.

Community Safety

Two impacts are identified in the public safety arena.

Impact C18: Community Safety Hazards Related with Increased Traffic

As mentioned above, construction activities will result in a significant increase in traffic on local and regional roads, which currently have limited vehicular use. A traffic management plan will need to be developed so that routes taken by heavy load and other vehicles avoid inhabited areas to the extent possible. In addition, safety awareness campaigns, particularly among school children, will be needed in Fungurume, Tenke and concession area schools and communities. These measures are further discussed in the subsequent section.

Impact C19: Community Safety Hazards Related with Construction Activities

Most construction activities will take place within fenced areas. However, some exploration, drilling and related activities may take place outside of the main construction site, and could entail safety risks to third parties.

Social Fabric

Social fabric is a term that refers to the incidence of social pathologies and how they are managed. The following impacts relate to social fabric.

Impact C20: Increase in Crime and Other Social Ailments

Unless pro-actively managed, the anticipated influx of well-paid workers, including expatriates, whose pay is incommensurate with usual local incomes, may cause an increase in petty crime as well as in more significant offences, such as assault. In addition, an increase in prostitution is usually observed to accompany major construction projects such as the project. Finally, there is a potential for a rise in alcohol and drug abuse as well in response to any increase in general social tension.

Impact C21: Social Disruption Caused by Anticipated Compensation or Employment

Cash compensation will be paid for crops damaged by construction, and possibly for other losses as well, in accordance with the RAP. Jobs will be offered locally to community members.

In societies where poverty is overwhelming and cash is rare, the perspective of cash compensation and employment offers is usually observed to trigger a number of issues, such as the following:

- Attempts to manipulate counts and valuation fraudulently, for example through bribery of members on community consultation committees.
- Attempts by people in positions of authority to extort payments from recipients of compensation or employment.
- Attempts by people in charge of offering jobs to obtain bribes in exchange for job offers, and by prospective employees to bribe employment officers.
- Creation of two classes, of "haves" and "have-nots", with related jealousy, complaints, suspicion of bribery and favoritism, which may be fuelled by ethnic differences.

C4.1.3.4 Description of Potential Socio-economic Impacts during Operation

Many of the impacts already evaluated and described for the construction phase of the TFM project may also occur during operations. The nature of these impacts and the means for their mitigation do not differ substantively between the construction and operational project phases. Only the more notable of these impacts are therefore identified below.

Impact OP1: Restrictions of Access

See Impact C2 above.

Impact OP2: Increase in the Fiscal Resources of the Democratic Republic of the Congo Government at Different Levels

Taxes paid by TFM, as well as custom duties and other fiscal resources will result in a significant increase of the resources of the various levels of the DRC Government (DRC central government, Katanga province, and possibly Kolwezi district).

Impact OP3: Impacts of Heavy Traffic on Local Road Infrastructure

See Impact C17 above, and Section C2-13 on traffic impacts.

Impact OP4: Community Safety Hazards Related with Increased Traffic

See Impact C18 above, and Section C2-13 on traffic impacts.

C4.1.4 Cumulative Effects Assessment

The cumulative effects assessment considers the effects of existing conditions, plus the project, and other planned or reasonably foreseeable projects. No other projects are planned for within the TFM concession boundary, other than mining of the limestone quarry and the potential for the TFM project to expand to a production of 400,000 tonnes per year of copper. Therefore, the cumulative case considers mining of the quarry and other major deposits in the concession such as the Fungurume ore body. Together, these are termed the "expanded project" (Section A4.17).

Expansion of the project to a production rate of 400,000 tonnes per year of copper would include construction of a second processing plant and tailings storage facility north of the Fungurume deposits. A conceptual outline of the expansion is shown in combination with the proposed TFM project footprint in Figure A4.17-1. Because of the conceptual nature of the expanded project at this time, the following assumptions were made:

- Mining of oxide ore at the Fungurume, Goma, Kavifwafwaulu (Fwaulu) and Kwatebala hills.
- Expansion of the proposed Kwatebala processing plant to a production of 200,000 tonnes per year of copper.
- Construction of a second processing plant north of Fungurume with a production of 200,000 tonnes pre year of copper.
- Construction of an above-ground tailings facility north of Fungurume.
- Deposition of waste rock near the Goma, Kwatebala and Fungurume pits.

- Expansion of the construction camp and ancillary facilities as required.

Methods for the cumulative assessment follow (to the extent possible) those for the impact assessment. Cumulative socio-economic effects are described in terms of extent, duration, intensity, and probability, and assessed in terms of direction (positive or negative) and significance (low, medium, high). Potential cumulative effects are summarized below in Table C4.1-3.

There is considerable complexity in assessing the cumulative socio-economic effects of a project. Impacts, mitigation measures and even benefits can engender many interacting effects, both positive and negative, which are often difficult to identify (Geisler 1993; Barrow 2000). Given the conceptual nature of the expanded project scenario, the description of cumulative socio-economic effects is similarly broad and conceptual in nature. More specific and detailed assessments of potential socio-economic impacts would be required prior to any expansion of the project.

C4.1.4.1 Land Use

With the expansion of the Kwatebala plant, construction of a second processing plant north of Fungurume, and additional waste rock and construction camp facilities, there may be additional loss of income streams and means of livelihood (economic displacement) for affected farmers, including severed access to unaffected agricultural lands. Unless adequately compensated, this could also result in increased pressure on remaining lands, or entail land-related conflicts between local farmers and the project, or amongst local groups. Depending on the land and livelihood resources that are affected by an expanded project, preferable alternatives for compensation will need to be identified for affected peoples. This can include compensation, replacing that portion of land or livelihood resource affected, or other restoration measures.

People whose lands would be required for an expanded project would need to be resettled. The current project footprint will require resettlement for those individuals living in the villages of Mulumbu, Amoni and Kiboko. Processes and guidelines for additional resettlement would be outlined in an additional Resettlement Action Plan (RAP) for affected communities.

Impacts associated with the physical displacement and relocation of households or communities that may be required for an expanded project would remain of high significance.

Table C4.1-3 Potential Cumulative Effects of the Expanded TFM Project

Topic	Impact Description	Direction	Extent	Intensity	Probability	Duration	Significance Without Mitigation	Significance With Mitigation
land use / agricultural land	loss of agricultural land due to occupation by the expanded project, potentially resulting in loss of income streams and means of livelihood (economic displacement), pressure on land and land-related conflict	negative	local	high	certain	long-term	high	medium
land use / agricultural land	severed access to agricultural land remaining itself unaffected	negative	local	high	certain	long-term	medium	low
land use / physical displacement	physical displacement of households residing within the expanded project footprint or within the boundary of safety or environmental buffer zones	negative	local	high	certain	long-term	high	high
demography / workforce	strain on local housing, infrastructure and services, potentially detrimental to locals, resulting from a potential influx of job-seekers and workers from outside the area	negative	local	high	probable	short-term	high	medium
demography / workforce	development of spontaneous settlements (shantytowns) near the project facilities, or in the towns of Fungurume and Tenke, in relation with the influx of job-seekers and other in-migrants	negative	local	high	probable	short-term	high	medium
demography / workforce	risks of disruption and cultural conflict with locals resulting from a potential influx of job-seekers and workers from outside the area	negative	local	medium	probable	short-term	medium	low
demography / workforce	influx of predominantly male job-seekers and workers, potentially living alone, with associated risks that sexually transmitted diseases, including hiv/aids, may spread	negative	local	high	certain	long-term	high	medium
demography / workforce	training required for workforce may result in long-term improvement of local population employability	positive	regional	medium	probable	long-term	-	-
economy	inflation caused by the influx of well-paid construction workers, potentially detrimental to the poorest in the community	negative	regional	high	probable	short-term	medium	low
economy	loss of local income to diggers, buyers and the local economy in general caused by the interruption of unauthorized artisanal mining	negative	local	high	certain	short-term	medium	medium

Table C4.1-3 Potential Cumulative Effects of the Expanded TFM Project (continued)

Topic	Impact Description	Direction	Extent	Intensity	Probability	Duration	Significance Without Mitigation	Significance With Mitigation
economy	improvement in local household income due to employment at the project during construction	positive	regional	high	certain	short-term	-	-
economy	local and regional economic "boom" during construction	positive	regional	high	certain	short-term	-	-
economy	local and regional economic depression at the end of construction	negative	regional	high	certain	short-term	high	medium
economy	increase in fiscal resources available to local and non-local levels of government	positive	local, regional, national	high	certain	long-term	-	-
labor	labor conflicts at the end of construction when construction workers' work contracts are terminated	negative	local	high	probable	short-term	high	low
labor	spill-over of labor conflicts at the project to the neighboring communities	negative	local	high	probable	short-term	high	low
infrastructure	long-lasting improvements to local infrastructure due to infrastructure upgrades required for construction	positive	regional	medium	probable	long-term	-	-
infrastructure	local road infrastructure could be negatively affected by increased heavy load traffic	negative	local	low	probable	long-term	medium	medium
community safety	safety hazards to neighboring communities in relation with increased traffic along the roads used by project traffic	negative	local	medium	probable	short-term	high	medium
community safety	safety hazards to neighboring communities in relation with construction activities at construction sites	negative	local	medium	probable	short-term	high	medium
social fabric	increase in crime and other social ailments (alcoholism, prostitution, drug use) caused by an influx of outsiders perceived as well paid and an influx of job-seekers remaining unemployed	negative	local	medium	probable	short-term	medium	low
social fabric	social disruption caused by compensation (social jealousy, fraudulent activities aiming at maximizing compensation) and employment – gap between "haves" and "have-nots"	negative	local	medium	Probable	short-term	medium	low

C4.1.4.2 Demography/Workforce

An expanded project could result in potentially greater impacts on local demography, and on local and regional workforces. The influx of a large workforce from outside the project area, as well as large numbers of job-seekers and migrants attracted to the project area, can potentially create impacts to local populations. Such potentially rapid changes in local demographics can result in the same types of undesirable pressures and consequences identified in previous sections. Measures that are directed towards addressing current project impacts (see Section D4.1, Social Management Plan) will be carried forward into any expanded project scenario.

The nature of potential interactions between local population movements, worker and migrant influx, and potential pressures on housing, infrastructure and social systems are difficult to predict. This area would require a specific and detailed assessment of potential impacts for an expanded project. Particular attention would need to be given to assessing, monitoring and addressing potential increased incidences of STDs and HIV/AIDS associated with increased worker and migrant influx. Given the potentially large workforce and in-migrant population that may result, impacts associated with population change and workforce requirements of an expanded project may increase from low to medium significance.

A potential positive impact of local workforce recruitment is the improved employability of those hired. Local recruitment and training would improve skills needed for better job performance and promotion, broaden the skill base of employees, and prepare them for new opportunities in the future.

The direct and indirect economic contribution of an expanded project through employment and job creation would likely exceed estimated contributions of the original project. Approximately four[2] new indirect jobs for each new direct employment position are estimated to be created in the DRC by the original project (Appendix C4.1-1). Many of these jobs will be created for people within the region of the project. As it is difficult to predict far in advance the nature of direct and indirect employment, it would be reasonable to assume that an approximately similar employment and job creation multiplier may result from an expanded project. Salaries for locally hired residents would subsequently benefit both household and local economies through increases in purchasing power, and by directing economies away from barter exchanges.

[2] Note: This does not include jobs created in the informal economy.

C4.1.4.3 Economy

It is difficult to predict far in advance the potential economic impacts of a project expansion. For the original project, it is estimated that a total of approximately 643 million USD will be spent during the construction of the project. Of this, approximately 75 million USD will be spent in the DRC. Taxation over the life of the project will amount to approximately 18 million USD per year, allocated to local, regional and national governments. An expanded project would more than likely benefit from economies of scale in construction, and efficiencies in labor and production. Assuming such efficiencies, the economic effects of project expansion through expenditures and taxation may be anywhere between two to four times those of the original project.

Because potential project expenditures and revenues would be expected to be comparatively large relative to the size of the local and national economy, the economic benefit of an expanded project would be considered of high consequence.

While potential economic benefits from an expanded project are likely to increase, other economic impacts are also likely to be greater. Inflation caused by a greater influx of workers with relatively higher purchasing power may result in greater impacts on prices of housing, staples, and other basic goods and services. Construction completion and the termination of work and procurement contracts could potentially intensify any local and regional economic depression that may occur at the end of construction. Such impacts are most detrimental to the local population, particularly to the poorest in the communities.

Long-term monitoring of trends in local prices and the mitigation of impacts to the poorest members of the local community would be required along with an expanded CDP. Construction completion and subsequent demobilization of workers and local suppliers would require careful advance planning and consultations in order to minimize potentially greater downside economic effects.

C4.1.4.4 Labor

An expanded project would necessarily increase the number of labor and procurement contracts required. Greater investment in compliance with national and international labor standards, and ongoing monitoring and consultations will be required to reduce the potential negative impacts of labor, but also to enhance the benefits of increased employment, at the household, local and regional levels.

C4.1.4.5 Infrastructure

Construction associated with the expanded project would require infrastructure upgrades in the power, road, communications, and water supply sectors, which would remain after the end of construction and be beneficial to the communities in the concession area and beyond.

There are, however, likely to be greater impacts on road infrastructure as a result of increased traffic from construction and operation of the expanded project. Depending on the timing of construction, increases in heavy vehicle traffic along mine access routes could increase significantly over original project estimates. Truck and bus traffic could increase by as much as four-fold over original project estimates during construction and operations (see Section C2.13 for discussion of project-related traffic impacts). Both the high volumes of heavy trucks and buses along the routes throughout the life of the expanded project, and the potential wear on roadways caused by even further increases in heavy vehicle traffic would require specific mitigation measures.

The potential impacts on road infrastructure associated with an expanded project may increase from low to medium significance.

C4.1.4.6 Community Safety

Increases in heavy vehicle traffic along the mine's access routes are likely to be the greatest source of cumulative impacts on community safety. Considerable potential increases in heavy vehicle and bus traffic during construction and operations of an expanded project could result in proportional increases in person-vehicle interactions and potential accidents. Given the high volume of bicycle and pedestrian traffic currently along the access routes, measures that will reduce wear on roads that are currently in poor condition will be necessary to mitigate potential cumulative effects. The implementation of specific safety measures, which could include speed limits, drivers' education, public education, and scheduling and maintenance of vehicles, would reduce potential impacts.

Given potential traffic volume increases, along with potential population increases in the expanded project area that would likely result from the project, potential impacts on community safety may potentially increase from low to medium significance.

C4.1.4.7 Social Fabric

Given the fourfold expansion in the construction and operation workforce that would likely be required under a 400,000 tonnes per year scenario, additional

specific measures would be necessary in order to adequately address potential social disruptions associated with an expanded project. Such measures – which would also assist in addressing other workforce, demographic, and labor impacts – may potentially include (though not be limited to):

- Implementation of a workers' code of conduct.
- Accommodation of non-local workers in a dedicated construction camp.
- Establishment of a fair compensation mechanism.
- Transparent and publicly disclosed employability and hiring policies.

C4.1.5 Conclusion

C4.1.5.1 Socio-economics

Consultation results indicate that socio-economic opportunities created by the mine are a main concern. This includes individuals who expect to directly benefit, but also those people (particularly rural villagers and women) who view employment as less of a project benefit. For these people, assistance with agriculture, education, health services, water, electricity and housing are the expected benefits of project development.

There is considerable complexity in assessing the socio-economic impacts of a project. Impacts, mitigation measures and even benefits can engender many interacting effects, both positive and negative. Managing socio-economic impacts, more so than other disciplines, involves the mitigation of negative effects, and the enhancement of positive benefits.

C4.1.5.2 Land Use

Impacts related to land use include impacts to livelihoods and residences. The loss of agricultural land due to occupation by the project may result in the loss of agricultural income and livelihoods, increased pressure on other farms lands, or land-related conflicts. Depending on the land and livelihood resources that are affected by the project, preferable alternatives for compensation will be identified for affected peoples. This can include compensation, replacing that portion of land or livelihood resource affected, or other restoration measures.

Where access to otherwise unaffected land may become difficult for users, consultations will identify preferred alternatives for addressing impacts. This can range from the provision of footpaths or other means of access, to the inclusion of stranded or 'orphaned' parcels of land in eligibility for compensation or

replacement. In each case, the intent is to ensure that peoples' social and economic wellbeing are not harmed by project impacts.

Where permanent residences fall within the project footprint, residents will be physically displaced. People whose lands are required for the project will be resettled as per the Resettlement Action Plan (RAP). The village of Mulumbu will be impacted, and all of the approximately 1,200 individuals in the village will be resettled. This impact will also apply to the villages of Amoni and Kiboko. Criteria that will guide TFM resettlement planning are derived from the policies and guidelines of the Equator Principles and the IFC Performance Standard 5, which would address the following issues:

- Both economic (e.g., farm fields) and physical (e.g., homes) displacement will be addressed if resettlement planning is needed.
- If the source of any individual's livelihood is affected by more than 10 percent (more than 10 percent of their farm fields), the replacement of that livelihood and not simple cash compensation will be required.
- Affected people must be left no worse off, and preferably better off by the project.
- Losses must be compensated at full replacement cost and informal occupation rights will be taken into consideration.
- If a resettlement plan is needed it will be carried out in a consultative manner, particularly when it comes to the selection of resettlement sites, with the affected people, the host communities and local authorities, the objective being to reach broad community consensus.
- The RAP will be tied to the ESIA process, and provisions will be made for long-term monitoring of affected people and their livelihoods.

C4.2 CULTURAL HERITAGE

C4.2.1 Introduction

This section presents the assessment for the effects of the Tenke Fungurume Mining (TFM) project on cultural heritage, as per the project's terms of reference (Appendix E8). The information presented includes details on:

- Locations of all known cultural heritage sites as discovered by archaeological and sociological survey methods.
- Locations of any cultural heritage sites that will likely be impacted by the TFM project.
- Mitigations measures incorporated in the project design to minimize cultural heritage impacts.

This section is organized as follows:

- Section C4.2.2 describes the study areas.
- Section C4.2.3 discusses the approaches and results for the impact and the sustainability assessments.
- Section C4.2.4 provides the cumulative effects assessment.
- Section C4.2.5 discusses the conclusions of the assessment.

Baseline information concerning cultural heritage is provided in Section B4.2.

A glossary of terms and acronyms used in this section is provided at the back of this volume.

C4.2.2 Study Areas

The study areas for the cultural heritage impact assessment are the same as those for the cultural heritage baseline, which follow the Regional Study Area (RSA) and Local Study Area (LSA) used by the terrestrial study areas for the project (Section C1.9). The LSA has a 500-meter buffer surrounding all project alternatives. Specific locations of investigation are addressed in the methods section.

C4.2.3 Impact Assessment

C4.2.3.1 Issue Scoping

The potential key issues relating to cultural heritage are:

- Initial removal and disturbance of unique or important cultural heritage sites during mine construction (primary impacts).
- Disturbance of nearby cultural heritage sites during and after mine operation (secondary and tertiary impacts).

Cultural heritage 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 project.

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 heritage lie next 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.

C4.2.3.2 Key Questions and Indicators

Two key questions were established to determine the social impact of the TFM project on cultural heritage. These key questions, listed in Table C4.2-1, address the aspects of impact assessment and sustainability assessment for cultural heritage.

Table C4.2-1 Key Questions for Cultural Heritage

Impact Assessment
CH-1 What effect will the project have on cultural heritage sites?
Sustainability Assessment
CH-2 How can the project have a positive effect on our knowledge of cultural heritage in the study area?

An indicator relating directly to cultural heritage is the impact of the TFM project on local cultural heritage. Indicators relating to socio-economic effects are addressed in the environmental and social impact assessment (ESIA) section (Section C4.1).

C4.2.3.3 Assessment Criteria

Assessment criteria for cultural heritage are presented in Table C4.2-2. The screening system for sustainability consequence is provided in Section A5.

Table C4.2-2 Impact Description Criteria for Cultural Heritage

Direction[a]	Magnitude[b]	Geographic Extent[c]	Duration[d]	Reversibility[e]	Frequency[f]
neutral: no effect on cultural heritage **negative:** cultural heritage are destroyed **positive**: cultural heritage sites are found, protected and/or studied.	**negligible:** no physical impact occurs or no historical sites are expected to be present **low:** minimal impact to valuable resources, or resources are few and of low value **moderate:** moderate or partial impact to resources of high to moderate historical value **high:** severe physical impact to resources of high historical value	**local:** effect restricted to the LSA **regional:** effect extends beyond the LSA into the RSA **beyond regional:** effect extends beyond the RSA	**short-term:** greater than 3 years **medium-term:** 3 to 20 years **long-term:** less than 20 years	**reversible** or **irreversible**	not applicable

[a] Direction: positive or negative effect for measurement indicators as defined for the specific component.

[b] Magnitude: degree of change to analysis indicator.

[c] Geographic Extent: area affected by the impact.

[d] Duration: length of time over which the environmental effects occurs. Considers a two-year construction period and a 20-year operations period.

[e] Reversibility: effect on the resource (or cannot be reversed).

[f] Frequency: how often the impact occurs.

C4.2.3.4 Key Question CH-1

Key question CH-1 is: What effect will the project have on cultural heritage sites?

Linkage Evaluation

A cause and effect diagram for cultural heritage is presented in Figure C4.2-1. As earthmoving activities during the construction, operations and closure phases of the TFM project have the potential to affect cultural heritage sites, this linkage is valid. Soil erosion and changes to hydrology that may lead to changes in streambank morphology can also affect cultural heritage, as can increased visitation or use of the area due to induced development. These linkages are all valid.

Assessment Methods

Professional sociological and archaeological experience was used to determine the presence of cultural heritage sites within the LSA. Assessment methods consisted of identifying which cultural heritage discovered during the fieldwork phase would be directly impacted by project activities.

Potential secondary impacts relating to hydrologic or soil erosion effects within the project footprint were evaluated based on impacts predicted in the soils and hydrogeology impact sections (Sections C2.4 and C2.10).

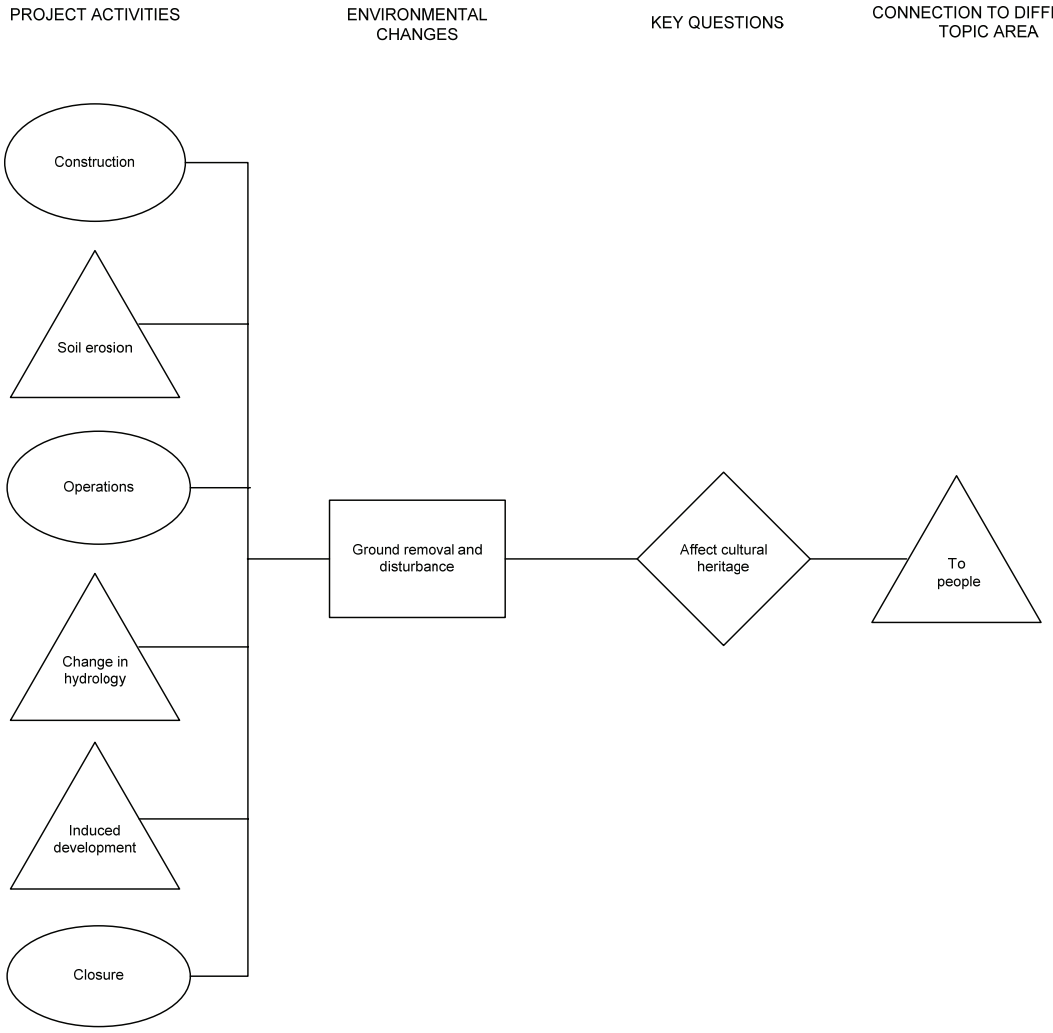
Cultural heritage may suffer tertiary impacts (through increased visitation to the area by non-local residents following construction of the project). Impacts due to induced development (Section C4.1) were used to qualitatively assess tertiary effects.

Mitigation

The following mitigation measures will be employed to minimize impacts on cultural heritage:

- Archaeological sites DKK, DGN, and DShN were judged sufficiently important that they were recommended for further investigation (including systemic excavation) should they be impacted by the TFM project (Section B4.2). However, it appears that DKK will not be subjected to impact, and DGN and DShN are in the buffer zone in the western periphery of the project area, and can thus also likely be avoided.
- Cult sites and a cemetery exist in the vicinity of Mulumbu, but are not in the impact zone of the TFM project. No sacred sites will be directly impacted by the project (Muya 2006; see Appendix B4.2-I).
- Tertiary impacts, should they occur, may be mitigated through educating non-locals of the local cultural practices and by ensuring that non-local workers avoid visiting cultural heritage sites adjacent to the direct impact zone of the TFM project.

Figure C4.2-1 Cultural Heritage Linkage Diagram



404000 408000 412000 416000 420000 424000 428000 432000

8836000 8832000 8828000 8824000

Mofia
Mulumbu Mutombo
Mpanga Ntadi
Kinyama
Kamungu Mulolwa
Kamungu Kitambo
Kabombwa
Kabombwa
Mwanga Muteba (Shungu)
Salabwe
Kasanga
Mano Mapia
Kanzanza
Mwela Mpande
Kyoni
Ndela Sase 2
Ndela Sase 1
Ndela Prudence
MLB
Amoni
Longe
Mulumbu Kiasa
Mulumbu
Kiboko
Kanzekenene
Ndela 1
Kasanga
DS
DSHN
DGN
Sokelweta
Shimpidi
LTD1
LTD1
Tenke
Dipeta
Kwatebala Gare
CP
Mwela Mpande Gare
MPL
Mpungulume
LTD2
DSP
DKK
Kabakishi
Fungurume
MPL
Katumba
Muta
DKL
Mpala
Kampangu
Kakapidi
Maoma
Kesanonga
Konia
Bloc Mitumba
Kafwaya
Kabwe Dikuku
Kabwe Kakese
Zakeo
Postolo
Mano Mapia/Nkonga
Mutaka Mwelwa, Q. Kibangu.
Kimilombe
Lutanda
Mutaka II
Kilusonsa

N

3 0 3
ÉCHELLE 1:80000 KILOMÈTRES
SCALE 1:80000 KILOMETERS

LÉGENDE / LEGEND

- SITE ARCHÉOLOGIQUE DE 1997 / 1997 ARCHAEOLOGY SITE
- SANCTUAIRE / SHRINE
- CIMETIÈRE / CEMETERY
- ÉTUDE 2006 / 2006 INVESTIGATION
- SITE SACRÉ / SACRED SITE
- VILLAGE
- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- ZONE D'ÉTUDE LOCALE / LOCAL STUDY AREA
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

COMPOSANTS DE PROJET / PROJECT COMPONENTS

- BANC D'EMPRUNT / BORROW PIT
- CHEMINS DE ROULAGE/ HAUL ROAD
- LIGNE DE TRANSPORT D'ÉNERGIE / POWER LINE
- ROUTE / ROAD
- VOIE D'ÉVITEMENT / RAILWAY SIDING
- PIPELINE / PIPELINE
- AÉROPORT / AIRFIELD
- CARRIÈRE / QUARRY
- CLÔTURE / FENCE
- FOSSE DE LA MINE/ MINE PIT
- LIMITES DE LA FUTURE L'IMPLANTATION / FUTURE EXPANSION BOUNDARY
- LIMITES DE L'USINE (ÉTAPE DE CONCEPTION) / PLANT DESIGN BOUNDARY
- PARC À RÉSIDUS / TAILINGS SITE
- PILE DE STOCKAGE - SOL / STOCK PILE - SOIL
- SITE D'ENFOUISSEMENT / LANDFILL
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- VILLAGE PERMANENT / PERMANENT VILLAGE

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE **SITES DU PATRIMOINE CULTUREL EN LIEN AVEC LE PROJET / CULTURAL HERITAGE SITES IN RELATION TO THE PROJECT**

Golder Associates
Calgary, Alberta

N° PROJET / PROJECT NO. 05-1334-035		ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	MR	30 May 2006	
GIS / SIG	RLP	04 Jan. 2007	
VÉRIFIÉ / CHECK	MR	31 Oct. 2006	
APPROUVÉ / REVIEW	MR	31 Oct. 2006	

FIGURE: C4.2-2

Impact Analysis

During construction, ground disturbance will occur at the mine and quarry areas, along new road routes, at the tailings storage facility, and at the processing plant site. No cultural heritage sites, including cemeteries, will be impacted by these activities.

Following the start-up of the TFM project, the increased presence of non-local workers in the region over the long term may lead to tertiary impacts on the local cultural heritage. These impacts may include profanation (purposeful or inadvertent) of local cultural heritage sites, stemming from cultural divides and/or misunderstandings. The overall social consequence will therefore be negligible (Table C4.2-3). During operation, potential tertiary impacts involving desecration of sites by non-locals may be of moderate magnitude (so long as sites are not destroyed), local in extent, and of medium-term duration (as long as the mine is in operation). The overall social consequence is rated as low.

Table C4.2-3 Residual Impact Classification for Key Question CH-1

Phase	Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Social Consequence
Key question CH-1: What effect will the project have on cultural heritage sites?							
construction	negative	negligible	local	long-term	yes	n/a	negligible
operation	negative	moderate	local	medium-term	yes	n/a	low

n/a = not applicable.

Prediction Confidence

The baseline status of cultural heritage in the LSA is well understood. Information concerning the effects of the mine and quarry areas, tailings storage facility, processing plant site and other infrastructure on known sites is sufficiently adequate to have a high confidence in the impact predictions in this section.

Monitoring

No monitoring is proposed specifically for cultural heritage.

C4.2.3.5 Key Question CH-2

Key question CH-2 is: How can the project have a positive effect on our

knowledge of cultural heritage in the study area?

Assessment Methods

In general, assessment methods are the same as for key question CH-1. Key question CH-1 emphasizes potential negative effects of losses of existing cultural heritage sites while key question CH-2 emphasizes the potential long-term benefits of impacts to these sites.

Mitigation

Although any cultural heritage site that cannot be relocated may be destroyed during the construction phase of the TFM, proper mitigation will ensure that valuable archaeological information is gained from this, which would be of benefit to local and extra-local interests. Such mitigative measures would include:

- Systemic excavation of sites DKK, DGN and DShN.
- Use of local experts.
- Assistance in preparation of display materials for the museum in Lubumbashi.
- Provision of school materials for local schools.
- Encouragement of local graduate students from the University of Lubumbashi.

Impact Analysis

The positive impacts that can occur from possible mitigation of sites DKK, DGN and DShN are deemed to be positive, because this would add greatly to our understanding of the region's pre-history.

Table C4.2-4 Residual Impact Classification for Key Question CH-2

Magnitude	Span or Reach	Duration	Probability of Success	Sustainability Consequence
Key question CH-2: How can the project have a positive effect on our knowledge of cultural heritage in the study area?				
high	entire community	long-term	high	high

Prediction Confidence

The long-term positive impacts to local cultural heritage are predicted with a high level of confidence.

Monitoring

No monitoring is proposed specifically for the cultural heritage key questions.

C4.2.4 Cumulative Effects Assessment

Linkage Evaluation

Should the TFM project be expanded from 115,000 tonnes per year production to 400,000 tonnes per year, the physical extent of ground disturbance would increase considerably with additional areas being mined and additional areas required for tailings storage facilities, waste rock facilities and processing plants.

Assessment Methods

Detailed plans for the additional development of the project to expand to 400,000 tonnes per year are not yet available. However, the general concept for such a development was reviewed in the context of known baseline conditions for cultural heritage. Professional experience was used to develop an understanding of the potential effects of an expanded TFM project, specifically in relation to the long-term (post-closure) changes in topography and geomorphology caused by mining, processing plant sites, waste rock facilities, the quarry, and linear developments such as roads. Principles developed for closure plans and other project goals to mitigate (minimize) long-term effects over the long term were considered in the assessment of long-term impacts.

Mitigation

An expanded 400,000 tonnes per year project would have to create a more detailed plan for cultural heritage site mitigation, following the methods proposed for key question CH-1.

Impact Analysis

For the cumulative development case, impacts will occur across much of the LSA and in additional ore-bearing hills outside of the LSA, such as the Fungurume hills. The expanded TFM project would cover considerably more land area than those in the project case assessed under key question CH-1. It is

assumed that a pre-disturbance survey for artifacts will occur and that the appropriate mitigation will take place. Consequently, the impacts for the cumulative case are predicted to be negligible in magnitude, although regional in geographic extent and long-term in duration (Table C4.2-5). The overall social consequence is predicted to be negligible.

Table C4.2-5 Residual Impact Classification for the Cumulative Case

Direction	Magnitude	Geographic Extent	Duration	Reversibility	Frequency	Social Consequence
Key question $CH_{(ce)}$-1: What effect will the expanded project have on cultural heritage?						
negative	negligible	regional	long-term	yes	n/a	negligible

n/a = not applicable.

Prediction Confidence

The baseline status of cultural heritage in the RSA is fairly well understood. Information concerning the effects of a larger, 400,000 tonnes per year project has been gathered by a study program that included survey work outside of the actual mine footprint. As such, a general understanding of the effects of such a project is in place. While further site-specific surveys would have to be conducted once the development plans are better understood, it is not anticipated that any sites would be found that could not be successfully mitigated. The prediction confidence for this assessment is rated as high.

C4.2.5 Conclusions

Residual impacts are summarized above in Tables C4.2-3, C4.2-4 and C4.2-5.

Following mitigation, the TFM project will have a negligible social consequence for cultural heritage during the construction phase, and a low consequence during the operation phase. Potential long-term negative impacts, due to the loss of specific existing cultural resource sites, are offset by possible positive mitigation practices such as excavation of prehistoric sites, or by neutral mitigation practices such as deconsecration and/or relocation of any affected sacred sites or cemeteries.

Excavation of some of the existing archaeological sites on the concession area would add to the understanding of the region's pre-history and could result in a high positive sustainability consequence.

Under the cumulative development case, a project expansion from 100,000 to 400,000 tonnes per year production may increase the risk of impacts on cultural heritage in direct proportion to the enlarged footprint. However, with the appropriate surveys and mitigation the social consequence is predicted to be negligible.

C5 SUMMARY

The low, moderate and high impacts of the TFM project are summarized in Table C5-1. Disciplines or key questions that have negligible effects or no effects are not included in this table. Details for all impacts are provided in Sections C2 through C4.

Table C5-1 Summary of Low, Moderate and High Impacts

Discipline	Key Question / Issue	Project Phase or Duration	Impact (Consequence) Level[(a)]
Topography and Geomorphology	TG-1 What effect will the project have on topography and geomorphology?	operation closure	moderate
	TG-2 How can the project influence topography and geomorphology to have a long-term positive effect?	long-term	moderate (positive)
	$TG_{(ce)}$-1 What effect will the project have on topography and geomorphology (cumulative case)?	long-term	high
Soils	SR-1 What effect will the project have on soil quality/productivity?	operation closure	moderate
	SR-2 What effect will the project have on loss of unique soils?	operation closure	high
	SR-3 How can the project have a long-term positive effect on soil quality/productivity? (agricultural credit, agroforestry, soil mulching, green manuring)	long-term	moderate (positive)
	$SR_{(ce)}$-1 What effect will the project have on soil quality/productivity (cumulative case)?	operation closure	low
	$SR_{(ce)}$-2 What effect will the project have on loss of unique soils (cumulative case)?	operation closure	high
Visual Aesthetics	VA-1 What effect will the Kwatebala mine, processing plant and associated infrastructure have on visual aesthetics?	construction	moderate
	VA-1 What effect will the Kwatebala mine, processing plant and associated infrastructure have on visual aesthetics?	operation closure	low to moderate
	VA-2 What effect will the access roads, power lines and limestone quarry have on visual aesthetics?	construction operation closure	low
	VA-3 What effect will the Goma mine and its associated facilities have on visual aesthetics?	construction operation	high
	VA-3 What effect will the Goma mine and its associated facilities have on visual aesthetics?	closure	moderate
	VA-4 How can the project influence the quality of the visual resource to have a long-term positive effect? (upgrading of villages due to improved socio-economics; creation of conservation area)	long-term	moderate (positive)
	$VA\text{-}5_{(ce)}$ What cumulative effect will the project have on visual aesthetics?	construction operations	high
	$VA\text{-}5_{(ce)}$ What cumulative effect will the project have on visual aesthetics?	closure	moderate to high

Table C5-1 Summary of Low, Moderate and High Impacts (continued)

Discipline	Key Question / Issue	Project Phase or Duration	Impact (Consequence) Level[(a)]
Major Hazards	TG-1 What effect will major hazards associated with the project have on the public and environment?	all	low risk rating as defined by risk matrix
Air	AQ-1 What effect will construction emissions have on air quality in the receiving airshed? (fugitive dust and air emissions)	operations	low
	AQ-2 What effect will emissions from operation of the proposed project have on sensitive receptors? (SO_2, NO_2, PM_{10}, CO, VOC, odor, acid mist)	operations	low
	AQ-2 What effect will emissions from operations of the proposed project have on sensitive receptors? (greenhouse gas emissions)	operations	moderate
	AQ-3 What effect will closure emissions (fugitive dust and combustion emissions) have on air quality in the receiving airshed?	closure	low
	AQ-4 How can the project have a long-term positive effect on the receiving airshed? (local electricity distribution, improvements to road system, household stoves, non-timber forest products)	long-term	moderate (positive)
	$AQ_{(ce)}$-1 What effect will cumulative operations have on air quality in the receiving airshed?	medium-term	moderate (PM_{10} and SO_2)
	$AQ_{(ce)}$-1 What effect will cumulative operations have on air quality in the receiving airshed?	medium-term	low (VOC, odor, SO_3); moderate (SO_2, PM_{10}, GHG)
Noise and Vibrations	All questions.	medium-term	no effects greater than negligible
Hydrogeology	GW-1 What effects will the project have on groundwater resources including groundwater levels, groundwater availability and groundwater discharge to springs and surface water (baseflow)?	long-term	moderate effect on far north and north aquifers
	GW-1 What effects will the project have on groundwater resources including groundwater levels, groundwater availability and groundwater discharge to springs and surface water (baseflow)?	medium-term	negligible to low effect on Dipeta, south and Tshilongo aquifers aquifer
	GW-2 What effect will the project have on groundwater quality? Specifically, how will seepage from mine facilities (tailings storage facility, waste rock facilities, ore stockpiles, and the processing plant area) affect groundwater quality? How will the post-closure pit lake affect groundwater quality?	long-term	low to moderate effect on far north, north and Dipeta aquifers
	GW-3 How can the project have a long-term benefit on groundwater quantity and quality? (groundwater supply systems)	long-term	high (positive)
	GW-3 How can the project have a long-term benefit on groundwater quantity and quality? (fee for service water utility, public education)	long-term	moderate (positive)
	$GW_{(ce)}$-1 What effects will the expanded project have on groundwater quantity and quality?	long-term	high
Water Quality	WQ-1 What effects will the project have on water quality indicators in local springs and watercourses?	long-term	low impacts for groundwater quality and in
	WQ-1 What effects will the project have on water quality indicators in local springs and watercourses?	short-term	sedimentation and quality of runoff during storm events
	WQ-4 How can the project have a positive effect on water and sediment quality?	long-term	high (positive) impact for sanitation and hygiene program

Table C5-1 Summary of Low, Moderate and High Impacts (continued)

Discipline	Key Question / Issue	Project Phase or Duration	Impact (Consequence) Level[(a)]
Water Quality	$WQ_{(ce)}$-1 What effect will the project have on water quality in local watercourses (cumulative case)?	long-term	low impacts for groundwater quality and in
	$WQ_{(ce)}$-1 What effect will the project have on water quality in local watercourses (cumulative case)?	short-term	sedimentation and quality of runoff during storm events
Flora	FL-1 To what extent will the project result in loss or alteration of plant communities and reduced species diversity (effect of clearing activities)?	construction and operation	high for copper-cobalt rock outcrop and steppe-savannah (although critical habitat is not significantly affected) moderate for miombo woodland; low for gallery forest and wetland
	FL-1 To what extent will the project result in loss or alteration of plant communities and reduced species diversity (effect of clearing activities)?	closure	moderate (positive) for degraded miombo woodland and low (positive) for copper-cobalt steppe-savannah and gallery forest
	FL-1 To what extent will the project result in loss or alteration of plant communities and reduced species diversity (effect of changes to soils, hydrology, groundwater, air quality and exotic species)?	construction and operation	moderate (soil and hydrology and groundwater for gallery forest), low (exotic species)
	FL-2 Will the project increase the risk of loss of plant species (species extirpation or extinction)?	long-term	low
	FL-3 How can the project reduce the rate of miombo woodland and gallery forest degradation?	long-term	low (positive) for agroforestry and moderate (positive) for non timber forest products
	$FL_{(ce)}$-1 To what extent will the project result in loss or alteration of plant communities and reduced species diversity?	construction and operation	high for copper-cobalt rock outcrop and copper-cobalt steppe-savannah; low for gallery forest, miombo woodland and wetland; low impact of air quality
	$FL_{(ce)}$-2 Will the project increase the risk of loss of plant species (species extirpation or extinction)?	long-term	moderate
Fauna	FA-1 What effect will the project have on fauna habitat?	long-term	moderate impacts due to site clearing and edge effects
	FA-1 What effect will the project have on fauna habitat?	medium-term	low effects due to sensory disturbance; negligible to low effects due to changes in water flows and quality
	FA-2 What effect will the project have on fauna dispersion and movement?	long term	low
	FA-3 What effect will the project have on fauna demography?	long term	moderate due to site clearing mortality; high impact due to increased hunting and collecting
	FA-3 What effect will the project have on fauna demography?	medium-term	moderate impact due to increased vehicle collisions

Table C5-1 Summary of Low, Moderate and High Impacts (continued)

Discipline	Key Question / Issue	Project Phase or Duration	Impact (Consequence) Level[(a)]
Fauna	FA-5 How can the project have a positive effect on the habitats and associated fauna of the area?	long-term	moderate (positive) impact for education; low (positive) impact for conservation area
	$FA_{(ce)}$-1 What effect will the expanded project have on fauna?	long-term	high
Fish and Aquatic Habitats	FAH-1 What effect will the project have on aquatic habitat (effects of habitat displacement, water quality and water volume changes)?	construction closure	low
	FAH-1 What effect will the project have on aquatic habitat (effects of habitat displacement, water quality and water volume changes)?	operation	low to moderate
	FAH-2 What effect will the project have on fish and aquatic biota abundance?	construction	low effects for health and habitat modification
	FAH-2 What effect will the project have on fish and aquatic biota abundance?	operation	low effect for health and habitat modification at mine; moderate effect for habitat modification downstream
	FAH-3 What effect will the project have on subsistence fisheries?	construction operations	low effects on fish availability and health
	FAH-3 What effect will the project have on subsistence fisheries?	closure	low (positive) effects on fish health and condition
	FAH-4 How can the project have a positive effect on aquatic habitat and subsistence fisheries?	long-term	low to moderate (positive) effect of catchment planning; moderate (positive) effect of education
	$FAH_{(ce)}$-1 What effect will the expanded project have on aquatic habitat?	long-term	moderate
Natural Habitats and Biodiversity	HB-1 What effect will the project have on biodiversity at the species level?	construction operation	high effect in copper-cobalt steppe-savannah and rock outcrop; low effect in miombo woodland and gallery forest
	HB-1 What effect will the project have on biodiversity at the species level?	closure	moderate effect in copper-cobalt steppe-savannah and rock outcrop; low effect in miombo woodland and gallery forest
	HB-2 What effect will the project have on natural habitats and biodiversity at the landscape level?	construction operation	high effect in rock outcrop; moderate effect in copper-cobalt steppe-savannah; low effect in miombo woodland and gallery forest
	HB-2 What effect will the project have on natural habitats and biodiversity at the landscape level?	closure	moderate effect in copper-cobalt steppe-savannah and rock outcrop complex; low effect in miombo woodland and gallery forest
	HB-3 How can the project influence natural habitats and biodiversity to have a long-term positive effect?	long-term	moderate (positive) effect from education; low (positive) effect from management area

Table C5-1 Summary of Low, Moderate and High Impacts (continued)

Discipline	Key Question / Issue	Project Phase or Duration	Impact (Consequence) Level[(a)]
Biodiversity	HBce-1 and HBce-2 What effect will the project have on biodiversity at the species and landscape level under the cumulative case?	construction operation	high effect in copper-cobalt steppe-savannah and rock outcrop; moderate effect in miombo woodland and gallery forest
	$HB_{(ce)}$-1 and $HB_{(ce)}$-2 What effect will the project have on biodiversity at the species and landscape level under the cumulative case?	closure	moderate effects on all habitats
Protected Areas	PA-2 How can the project influence protected areas to have a long term positive effect?	long-term	low to moderate (positive) for both regional protected areas and local protected areas
Socio-economics	loss of agricultural land due to occupation by the project, potentially resulting in loss of income streams and means of livelihood (economic displacement), pressure on land, and land-related conflict	construction operation	moderate
	severed access to agricultural land remaining itself unaffected	construction operation	low
	physical displacement of households residing within the project footprint or within the boundary of safety or environmental buffer zones	construction operation	high
	strain on local housing, infrastructure and services, potentially detrimental to locals, resulting from a potential in-flux of job-seekers and workers from outside the area	construction	moderate
	development of spontaneous settlements (shantytowns) near the project facilities, or in the towns of Fungurume and Tenke, in relation with the influx of job-seekers and other in-migrants	construction	low (moderate for cumulative case)
	risks of disruption and cultural conflict with locals resulting from a potential influx of job-seekers and workers from outside the area	construction	low
	influx of predominantly male job-seekers and workers, potentially living alone, with associated risks that sexually transmitted diseases, including HIV/AIDS, may spread	construction	moderate
	training required for workforce may result in long-term improvement of local population employability	construction operation	positive
	inflation caused by the influx of well-paid construction workers, potentially detrimental to the poorest in the community	construction operation	low
	loss of local income to diggers, buyers and the local economy in general caused by the interruption of unauthorized artisanal mining	construction operation	moderate
	improvement in local household income due to employment at the project during construction	construction	positive
	local and regional economic “boom” during construction	construction	positive
	local and regional economic depression at the end of construction	construction	moderate
	labor conflicts at the end of construction when construction workers’ work contracts are terminated	construction	low

Table C5-1 Summary of Low, Moderate and High Impacts (continued)

Discipline		Key Question / Issue	Project Phase or Duration	Impact (Consequence) Level[(a)]
Socio-economics		spill-over of labor conflicts at the project to the neighboring communities	construction	low
		long-lasting improvements to local infrastructure due to infrastructure upgrades required for construction	construction operation closure	positive
		local road infrastructure could be negatively affected by increased heavy-load traffic	construction operation	low (moderate for cumulative case)
		safety hazards to neighboring communities in relation with increased traffic along the roads used by project traffic	construction operation	low (moderate for cumulative case)
		safety hazards to neighboring communities in relation with construction activities at construction sites	construction	low (moderate for cumulative case)
		increase in crime and other social ailments (alcoholism, prostitution, drug use) caused by an influx of outsiders perceived as well paid and an influx of job-seekers remaining unemployed	construction operation	low
		social disruption caused by compensation (social jealousy, fraudulent activities aiming at maximizing compensation) and employment – gap between “haves” and “have-nots”	construction operation	low
		increase in fiscal resources available to local and non-local levels of government	operations	positive
Cultural Heritage	CH-1	What effect will the project have on cultural heritage sites?	operation	low
	CH-2	How can the project have a positive effect on our knowledge of cultural heritage in the study area? (Education and studies of local sites)	long-term	high (positive)

(a) Effects are negative unless otherwise indicated.

GLOSSARY

25x25	The standard measure for a plot of agricultural land in the concession area is 25 by 25 square meters. People also often use hectares to describe the size of the land.
7Q10	Lowest 7-day consecutive flow in a watercourse that occurs, on average, once every 10 years.
A horizon	The mineral horizon at or near the surface in which an accumulation of humified organic matter is mixed with the mineral material. Also, any plowed or disturbed surface layer. This is the part of the soil generally referred to as "top soil".
Acheulean	The Acheulean Tradition is an Old World Lower Paleolithic culture, dating from about 1.4 million years ago to approximately 100,000 years ago. Characterized by stone hand axes, the Acheulean tradition originated in Sub-Saharan Africa, such as at Olduvai Gorge.
Acid rain	A complex chemical deposition and atmospheric phenomenon that occurs when emissions of sulfur and nitrogen compounds and other substances are transformed by chemical processes in the atmosphere, often far from the original sources, and then deposited on earth in either a wet or a dry form. The wet forms, popularly called "acid rain" can fall as rain, snow, or fog. The dry forms are acidic gases or particles.
Acidification	The decrease of acid neutralizing capacity in water, or base saturation in soil, caused by natural or anthropogenic man-made processes. Acidification is exhibited as the lowering of pH, a process that can adversely affect aquatic life.
Acoustics	The science or study of sound.
ACRU	The Agriculture Catchments Research Unit hydrological runoff modeling software package used to simulate flow in streams.
Acute	A stimulus severe enough to rapidly induce an effect; in aquatic toxicity tests, an effect observed in 96 hours or less is typically considered acute. When referring to aquatic toxicology or human health, an acute effect is not always measured in terms of lethality.

Acute effect	A stimulus severe enough to rapidly induce an effect.
Ad hoc	For or concerned with a particular purpose or case, without general application.
Adaptation	Changes in the organism's structure or habit that help it adjust to its surroundings.
Aggregate	Composed of a mixture of minerals separable by mechanical means such as sand or stone, used in making concrete.
Agricultural mosaic	An area containing different agriculture classes, grassland and forest extensions.
Agroforestry	A dynamic, ecologically based natural resources management system that, through the integration of trees in farmland and rangeland, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels.
AIDS (Acquired immune deficiency syndrome)	A disease, caused by a virus transmitted in body fluids, in which there is a severe loss of cellular immunity leaving the sufferer susceptible to infection and malignancy.
Air-blast	Air blast (or air concussion, or air vibrations) is a pressure wave traveling through the air produced by the direct action of the explosive on air or the indirect action of a confining material subjected to explosive loading.
Airborne particles	Total suspended particulate matter found in the atmosphere as solid particles or liquid droplets. Airborne particulates include windblown dust, emissions from industrial processes, smoke from the burning of wood and coal, and the exhaust of motor vehicles.
Alkalinity	A measure of water's capacity to neutralize an acid. It indicates the presence of carbonates, bicarbonates and hydroxides, and less significantly, borates, silicates, phosphates and organic substances. It is expressed as an equivalent of calcium carbonate. The composition of alkalinity is affected by pH, mineral composition, temperature and ionic strength. However, alkalinity is normally interpreted as a function of carbonates, bicarbonates and hydroxides. The sum of these three components is called total alkalinity.

Alpha diversity	The diversity within a particular area or ecosystem; usually expressed by the number of species (i.e., species richness) in that ecosystem.
Ambient	Refers to conditions in the environment. For example, ambient air quality represents outdoor concentrations as opposed to indoor air quality, which represents the conditions inside building and structures. As well, the conditions surrounding an organism or area.
Ammonia	A pungent, colorless gaseous alkaline compound of nitrogen and hydrogen that is soluble in water, lighter than air, and can easily be condensed to a liquid by cold and pressure.
ANC (Acid neutralizing capacity)	The equivalent capacity of a solution to neutralize strong acids. ANC can be calculated as the difference between non-marine base cations and strong anions. This is the principal variable used to quantify the acid-base status of surface waters. Acidification is often quantified by decreases in ANC, and susceptibility of surface waters to acidic deposition impacts is often evaluated on the basis of ANC.
Anisotropic	The condition of having different values of hydraulic conductivity (in particular) in different directions in geologic materials. This is especially apparent in fractured bedrock or layered sediment.
Anticline	An arch-shaped fold in rock in which rocks layers are upwardly convex. The oldest rock layers form the core of the fold and outward from the core progressively younger rocks occur.
A-pan	A-pan refers to the instrument that is used to measure evaporation. Different kinds of instruments are used throughout the world such as the symons pan (S-pan). The A-pan is a circular pan measuring 47.5 inches across and 10 inches deep. The pan is filled with water at the beginning of the day and the drop in water level during the day represents the A-pan evaporation for that day.
Aquifer	In hydrogeology, a rock layer or sequence that contains water and releases it in appreciable amounts.
Artifact	Portable items that have been modified by people at some time in the past, such as projectile points, stone flaking debris, cut and modified bone and ceramics.

Artisanal fisheries	Fishing that occurs only in rivers and lakes and is mostly an informal activity carried with no official permits.
Artisanal mining	The term "artisanal" is widely used to distinguish between non-mechanized and mechanized production techniques, and in the economic development literature has most often been applied to the fisheries and mining sectors. The United Nations has reported that several attributes can be used to identify artisanal mining activity, including absence or low degree of mechanization, low safety standards, poorly trained personnel, low pay scale, low productivity, chronic lack of capital, illegality due to mining without concession rights, or little consideration of environmental impact. The Democratic Republic of the Congo (DRC) government and its multilateral stakeholders have sought to address problems posed by the artisanal mining sector through specific provisions of the 2002 Mining Code. The mining legislation provides a definition of artisanal exploitation as "any activity by means of which a person of Congolese nationality carries out extraction and concentration of mineral substances using artisanal tools, methods and process, within an artisanal exploitation area limited in terms of surface and depth up to a maximum of thirty meters" (Article 1, Definition of Terms). The 2002 Mining Code and its accompanying regulations further include requirements for how individual artisanal mining licenses may be obtained, and for how an "artisanal exploitation area" can be established; the latter including prohibition of the activity on mineralized areas that are otherwise commercially feasible for mining by industrial methods. All artisanal mining conducted in the Tenke Fungurume concession area is unauthorized and illegal.
Asymptote	A straight line associated with a curve such that as a point moves along an infinite branch of the curve, the distance from the point to the line approaches zero and the slope of the curve at the point approaches the slope of the line.
Atmospheric dispersion	The physical process that transports and disperses air emissions, resulting in increased concentrations and direct effects to air quality.
Attenuation	Reduction in the volume or intensity of sound.

A-weighted	The frequency range that is most sensitive to the human ear.
B horizon	The mineral horizon below a 0, A, or E horizon. The B horizon is in part a layer of transition from the overlying horizon to the underlying C horizon. The B horizon also has distinctive characteristics, such as (1) accumulation of clay, sesquioxides, humus, or a combination of these; (2) granular, prismatic, or blocky structure; (3) redder or browner colors than those in the A horizon; or (4) a combination of these.
Backwater	A small, generally shallow body of water attached to the main channel, with little or no current of its own. A body of stagnant water connected to a river.
Base flow	Base flow in rivers is the flows that are seen when there has been no rainfall for some time. Usually rainfall events will generate “storm flow” which is characterized by flow spikes. Once the flow spikes have subsided, base flow conditions will predominate.
Base saturation	The extent to which the exchange sites of a material are occupied by exchangeable basic cations; expressed as percent of the cation exchange capacity.
Basement rock	Igneous or metamorphic rock lying in sedimentary formations in the earth crust.
Benthic algae	Algae that live on the bottom of watercourses or waterbodies.
Beta diversity	A comparison of diversity between ecosystems, usually measured as the amount of species change between the ecosystems.
Bioaccumulation	To become concentrated inside the bodies of living things. Typically occurs with passage up through a food chain.
Bioassay	Using living organisms to measure the effect of a substance, factor or condition by comparing before-and-after data.
Bioavailability	The amount of chemical that enters the general circulation of the body following administration or exposure.

Bioavailable	A substance in a chemical and physical form that allows it to affect organisms or be accumulated by them. As well, it is the portion of a nutrient (or other chemical) that can be absorbed, transported, and utilized physiologically.
Biodiversity	The term used to describe the variety of life forms, the ecological roles they perform, and the genetic diversity they contain. Biodiversity therefore refers to the differences within and between all living organisms at their different levels of biological organization - genes, individuals, species and ecosystems. Three ways of measuring biodiversity are **Alpha diversity**: the diversity within a particular area or ecosystem; usually expressed by the number of species (i.e., species richness) in that ecosystem; **Beta diversity**: a comparison of diversity between ecosystems, usually measured as the amount of species change between the ecosystems; and **Gamma diversity:** a measure of the overall diversity within a large region.
Biological control	The use of animals and organisms that eat or otherwise kill or outcompete pests.
Biome	A major regional or global biotic community characterized by a specific climate and dominant forms of plant life.
Biota	Plant and animal life in a particular region.
Biotope	An area with generally uniform environmental conditions.
Broad-crested weir	A type of weir structure with a thick crest. The broad-crested weirs on site are one meter thick.
C horizon	The mineral horizon or layer, excluding indurated bedrock that is little affected by soil-forming processes and does not have the properties typical of the overlying horizon. The material of a C horizon may be either like or unlike that in which the solum (the upper layers of the soil profile, affected by climate and vegetation) formed.
Cadastral office	Agencies that maintain cadastral survey and historical data on lands patented, along with information on the mineral estate, resource conditions, and permits or leases.

Canopy forest	Canopy forest is a type of forest that contains *canopy* trees which are the tallest trees in a forest which are distinguished from *secondary* trees which occupy a lower ecological niche.
Capacity building	Actions that improve nonprofit effectiveness. The concept of capacity building in nonprofits is similar to the concept of organizational development, organizational effectiveness and/or organizational performance management in for-profits. Capacity building efforts can include a broad range of approaches, e.g., granting operating funds, granting management development funds, providing training and development sessions, providing coaching, supporting collaboration with other nonprofits, etc.
Catchment	The area of land drained by a creek or river system, or a place set aside for collecting water which runs off the surface of the land. Catchments provide the source of water for the reservoirs that collect draining water. Synonymous with watershed.
Catena	A series of associated habitats.
Catenal slope	A series of associated habitats along a slope.
Cathode	A cathode is a rectangular plate of metal, produced by electrolytic refining, which is melted into commercial shapes such as wirebars, billets, ingots, etc. A cathode is also the electrode at which electrons go into a cell, tube or diode, whether driven externally or internally.
CEC (Cationic exchange capacity)	The total amount of exchangeable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams (meq/100 g) or cmol kg^{-1}, usually when the soil is at neutral pH.
Centimole	One hundredth of a mole.
Ceramic	Clay artifacts, such as vessels, that have been intentionally fired.
Channel	An area that contains continuously or periodically flowing water that is confined by banks and a stream bed. The bed of a stream or river.
Chef de poste	Civil administrators of rural townships.

Chef de cité	Civil administrators of rural townships.
Chef de groupment	Traditional authorities who supervise several village populations.
Chef de quartier	Neighborhood representatives of chefs de posts or chefs de cité.
Chef de terre	Traditional authorities of chefs de posts or chefs de cité.
Chronic	The development of adverse effects after extended exposure to a given substance. In chronic toxicity tests, the measurement of a chronic effect can be reduced growth, reduced reproduction or other non-lethal effects, in addition to lethality. Chronic should be considered a relative term depending on the life span of the organism.
Chronic effect	An effect marked by long duration or frequent recurrence.
Cleanup	Actions taken to deal with a release or threat of release of a hazardous substance that could affect humans, the environment, or both.
Climate	A measure of the long-term averages, that is normal of key atmospheric variables such as temperature, precipitation and wind.
Climate normals	Long-term average conditions of temperature and precipitation.
cmol	Centimole charge of saturating ion per kilogram of soils. Cation exchange capacity is sometimes expressed in terms of cmol kg^{-1}. The cmol weight of the ions commonly found in soils is easily calculated by knowing the relative atomic mass of the ion divided by 100 and the charge on the ion.
Commensalism	A type of symbiosis in which two organisms are associated in a relationship in which one benefits from the relationship and the other is not substantially affected.
Compensation	Measures taken where mitigation techniques and other measures are not adequate to offset or counterbalance project effects.
Concentration	Quantifiable amount of a chemical in environmental media.

Concession area	A grant of land or property especially by a government in return for services or for a particular use. Defined in this ESIA to represent the two TFM concessions in the Democratic Republic of the Congo.
Conductivity	A measure of a waterbody's capacity to conduct an electrical current. It is the reciprocal of resistance. This measurement provides the limnologist with an estimation of the total concentration of dissolved ionic matter in the water. Measurement of conductivity provides a quick check of the alteration of total water quality due to the addition of pollutants to the water.
Confined space	A confined space is an enclosed or partially enclosed space that is not primarily designed or intended for human occupancy; has a restricted entrance or exit by way of location, size or means; and can represent a risk for the health and safety of anyone who enters.
Congolese franc (Fc)	At the time of the study the rate varied between 430 and 450 Fc for a United States dollar.
Contact water	Water that has come into contact with ore, waste rock or fuel or material handling areas and may contain elevated levels of constituents of concern.
Continuous cast copper rod	The key material used in the manufacturing of wire and cable products.
Conversion rates (for vegetation)	Strategies for converting dominant vegetation typically found on older surface mined benches to more favorable forages that can be more effectively utilized by livestock.
Copper cathode	Electrolytically refined copper is produced in the form of copper cathodes of 99.9 percent purity which may be shipped as melting stock to mills or foundries. Cathodes may also be cast into wire rod, billets, cakes or ingots, generally, as pure copper or alloyed with other metals.
Copper hills	Hills in the copper belt of the Democratic Republic of the Congo (Katanga) where heavy metal-rich outcrops occur.
Copper-cobalt flora	Plant communities of the copper/cobalt mineralized outcrops in the copper belt. Different plant communities are all controlled by the nature of the substratum and its chemical composition. Those communities are important because they include some plants unknown from other mineralized sites in the copper belt.

Core habitat	Area of a habitat type not affected by defined edge effects.
Cr horizon	Soft, consolidated bedrock beneath the soil.
Criteria continuous concentration	Estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.
Criteria maximum concentration	Estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect.
Critical natural habitats	The International Finance Corporation (IFC) defines critical natural habitats as areas with existing protection, including (1) areas designated as protected (such as national parks and reserves), (2) areas providing sustainable natural resources for traditional local communities, and (3) areas identified on a supplementary list prepared by the World Bank Group or other authoritative sources (as determined by IFC).
Critically endangered	Based on World Condervation Union (IUCN) criteria, a taxon is Critically Endangered when the best available evidence indicates that it meets any of the criteria A to E for Critically Endangered, and it is therefore considered to be facing an extremely high risk of extinction in the wild.
Croise rouge	Local people who have received some basic health training through the Red Cross.
Cropping	Cultivated plants or agricultural produce, such as grain, vegetables, or fruit, considered as a group or the total yield of such produce in a particular season or place.
Cult sites	A shrine, where each day the chief of the village goes to pray (morning and night preferably). He also goes there to have sacrificial meals. This area may be considered a church, temple, or simply a place for prayer.
Cultural heritage	The qualities and attributes of places or objects that have aesthetic, historic, scientific or social value for past, present or future generations. These values may be in a place's physical features, but can also be intangible qualities such as people's associations with, or feelings for, a place or object.

Cumulative effect	The impact on the environment which results from the incremental impact of the project when added to other past, present, and reasonably foreseeable future actions regardless of what agency, company or person undertakes such other actions.
Cyanophiceae	Class of the cyanobacteria division.
Dambo	A rich soil type found within the concession area.
dBA	A decibel value which has been A-weighted, or filtered to match the response of the human ear.
Decibel (dB)	A logarithmic scale for sound corresponding to a multiple of 10 of the threshold of hearing. Decibels for sound levels in air are referenced to an atmospheric pressure of 20 micro Pascals (μPa).
Dendrogram	A tree diagram that separates groups of vegetation on more superficial soils from groups of vegetation on more deep structured soils.
Deposit	A body of rock containing valuable minerals; usage generally restricted to zones of mineralization whose size has been wholly or partly determined through sampling.
Dewatering	To remove water from (a waste product or open pit mine, for example). As well, it is the process of natural, chemical, or mechanical removal of water from sludge, thereby reducing it to a damp solid with the lowest level of moisture attainable by the best available technology.
Dipeta syncline	Basin or trough-shaped fold in rock in which rock layers dip downward toward each other. The youngest rock layers form the core of the fold. Progressively older rocks occur outward from the core.
Direction	Positive or negative effect for measurement endpoints, as defined for the specific component.
Discharge	In hydrology, the discharge of a river is the volume of water transported by it in a certain amount of time. The unit used is usually cubic meters per second (m^3/s). The greater the discharge of a river, the more ability it has to carry sediment.

Dispersion model	A computerized set of mathematical equations that uses emissions and meteorological information to simulate the behavior and movement of air pollutants in the atmosphere.
Disposal	Final placement or destruction of toxic, radioactive or other wastes; surplus or banned chemicals, polluted soils and drums containing hazardous materials from removal actions or accident releases.
Diurnal mammals	Mammals that are primarily active during the day.
Dose	The amount of chemical that a person or animal may take into their body.
Drawdown	In hydrogeology, drawdown is a lowering of a reservoir or a change in hydraulic head in an aquifer, typically due to pumping a well.
Dump	A pile of broken waste rock or ore on surface.
Duration	Length of time over which an effect occurs.
EC_{20}	Effects Concentration (EC) is the concentration that results in a decrease of 20 percent of the measured variables.
Ecoregion	A relatively large recurring pattern of ecosystems associated with characteristic landforms, soils and biota.
Ecotone	The transition of physical and biological characteristics, from one community to the next. A transitional zone between two different biological communities.
Edaphic grassland	Grassland defined by soil type.
Edge effect	The modified environmental (climatic/abiotic or biological) conditions along the margins, or edges, of patches of one habitat type (often forest) surrounded partially or entirely by other habitat type (often cleared lands).
Effluent	An outflowing of water from a natural body of water, or from a man-made structure.

Electrofishing	A “live” fishing capture technique in which negative (anode) and positive (cathode) electrodes are placed in the water and an electrical current is passed between the electrodes. Fishes are attracted (galvano - taxis) to the anode and become stunned (galvano - narcosis) by the current, allowing the fish to be collected, measured and released.
Electrowinning	The electrodeposition of metals from their ores that have been put in solution or liquefied. Also called electrorefining or electroextraction.
Emergency	An event, or imminent event, outside the scope of normal operations that requires prompt coordination of resources to protect the health, safety, or welfare of people, or to limit damage to property and the environment.
Emergency preparedness	Activities, programs, and systems for response, recovery and mitigation in anticipated emergencies.
Endangered	Based on World Conservation Union (IUCN) criteria, a taxon is Endangered when the best available evidence indicates that it meets any of the criteria A to E for Endangered and it is therefore considered to be facing a very high risk of extinction in the wild.
Endangered species	A species facing imminent extinction or extirpation (no longer occurring in the country or region).
Endemic	Native or confined to a certain region.
Endemic species	Species which are restricted to a particular region and occur nowhere else.
Endemism	Being native to, and confined within the local region.
Endorheic	In geography, an endorheic basin is a watershed from which there is no outflow of water (either on the surface as rivers, or underground by flow or diffusion through rock or permeable material). Any rain (or other precipitation) that falls inside an endorheic basin remains there permanently, leaving the system only by evaporation. Endorheic basins are also called "internal drainage systems".

Entrainment	To carry suspended particles (for example) along in a current. In meteorology, the mixing of environmental air into a pre-existing organized air current so that the environmental air becomes part of the current.
Enviro bund	A dedicated constructed berm to limit access by humans and domestic animals to open pits.
Ephemeral	Lasting or living for a very short time. Having a very short life cycle.
Epicenter	The point on the Earth's surface immediately above where an earthquake was generated.
Equator Principles	A voluntary set of guidelines for managing environmental and social issues in project finance lending. The Equator Principles refer to guidelines developed by leading financial institutions such as the International Finance Corporation (IFC) and the World Bank.
Erodibility	A measure of the susceptibility of a soil to detachment by flowing water.
Erosion	The breaking down and subsequent removal of either rock or surface material by wind, rain, wave action, freezing and thawing, and other processes.
Erosivity	The capacity of falling or flowing water to erode land surfaces. Rainfall erosivity is defined by the computation of the values of rain erosivity factors based on the analysis of rainfall events.
ESMS	Environmental and social management system designed to manage mitigation and monitoring requirements for a project.
Esteva attenuation law	A law explaining how seismic activity is propagated or attenuated from a source to a site through the ground.
Eutrophic	The nutrient-rich status (amount of nitrogen, phosphorus and potassium) of an ecosystem.
Evapotranspiration	Loss of water from the soil both by evaporation from the soil surface and by transpiration from the leaves of the plants growing on it.
Ex situ	Growth of a species in a place not previously one of its native habitats.

Exchange acidity	The titratable hydrogen and aluminum that can be replaced from the adsorption complex by a neutral salt solution.
Exchangeable cations	A cation such as calcium that is adsorbed onto a surface, usually clay or humus, and is capable of being easily replaced by another cation such as potassium. Exchangeable cations are readily available to plants.
Expansion bolts	Bolts used to attach fixtures into concrete walls.
Exposure	The state of being exposed to something harmful.
Exposure pathways	The physical route by which a contaminant moves from a source to a biological receptor. A pathway may involve exchange among multiple media and may include transformation of the contaminant.
Extinct	A taxon (plant or animal) that is no longer alive or in existence.
Extirpation	The act of removing all members of a species from an area; as, the extirpation of weeds from land.
Fallow	Land left unseeded during a growing season. The act of plowing land and leaving it unseeded.
Fecal coliform	Bacteria that do not require but can use oxygen. Their presence in the water supply indicates recent contamination by human or animal feces.
Ferrasols	A group of soils in the United Nations Food and Agriculture Organization (FAO) soil classification system. They are very similar to Oxisols (United States Department of Agriculture [USDA] classification) in that they have at least one horizon with an almost complete decomposition of primary weatherable minerals and a clay fraction which is dominated by kaolinite and/or sesquioxides.
Ferricrete	A conglomerate consisting of superficial sand and gravel cemented into a hard mass by iron oxide derived from the oxidation of percolating solutions of iron salts.

Filterable residue	Materials in water that pass through a standard-size filter (often 0.45 microns). This is a measure of the "total dissolved solids" (TDS), that is chemicals that are dissolved in the water or that are in a particulate form smaller than the filter size. These chemicals are usually salts, such as sodium ions and potassium ions.
First order stream	A stream that has no tributaries emptying into it and normally originates from springs and/or seeps.
Fishery	The occupation devoted to the catching, processing, or selling of fish, shellfish, or other aquatic animals or a workplace where fish are caught and processed and sold.
Fly rock	Rock, mud or debris traveling in the air or along the ground as a result of a blast.
Focal depth	The depth from the earth's surface to the point of origin of an earthquake.
Foot-slope	Bottom of a slope.
Forbs	Broad-leaved herb, as distinguished from grasses.
Fossorial species	Burrowing or digging species.
FRAGSTATS	A spatial pattern analysis software program used to quantify the areal extent and spatial configuration of patches within a landscape. The analysis is done using categorical spatial data (e.g., plant communities).
Frequency	How often an effect occurs.
Fuelwood	A general term used to identify any woody biomass used as a fuel. It includes firewood, pellets and wood used for fuel in industry (e.g. wood chips, sawdust, shavings).
Fugitive emissions	Substances emitted from any source except those from stacks and vents. Typical sources include gaseous leakage from valves, flanges, drains, volatilization from ponds and lagoons, and open doors and windows. Typical particulate sources include bulk storage areas, open conveyors, construction areas or plant roads.
Funerary objects	Objects related to deaths, burials or funerals.
Gabions	Metal containers filled with stones, used in the construction of underwater foundations.

Gallery forest	A forest growing along a watercourse sometimes in an otherwise treeless region. Gallery forest often forms a corridor along a river system. A type of riparian forest.
Gamma diversity	A measure of the overall diversity within a large region.
Gauge plates	A steel plate that resembles a large ruler. It has graduated markings. The gauge plate is fixed into the river bed and the water levels are read off the gauge plate.
Gauging weir	A concrete structure built in the river bed to obstruct the flow of water. Water will flow over the weir in a desired location, where the depth of this flow is measured. Simple hydraulic calculations are used to convert this depth into a flow.
Genetic drift	Random changes to the genetic material in isolated populations.
Geographic extent	Area affected by the impact.
Geomembrane	A product, often made of polyvinyl chloride (PVC) or high density polyethylene (HDPE) that is used to limit seepage from or rainfall into a pond or other disposal facility.
Geomorphology	Scientific discipline concerned with the description and classification of the earth's topographic features.
Geotechnical	Refering to the use of scientific methods and engineering principles to acquire, interpret, and apply knowledge of earth materials for solving engineering problems.
Germination	The first stage in the development of a plant from a mature seed characterized by the emergence of a stem and root.
Glides	A calm stretch of shallow water flowing smoothly.
Graminoid	Grasses and grasslike plants such as sedges and rushes.
Gravity units	Units of acceleration, usually in meter per second squared.

Green manuring	Green manuring is the plowing under or soil incorporation of any green manure crops while they are green or soon after they flower. Green manure is forage or leguminous crops that are grown for their leafy materials needed for soil conservation. It is an effective way of increasing the humus content of the soil.
Greenhouse gases	Gaseous components of the atmosphere that contribute to the greenhouse effect. The major natural greenhouse gases (GHG) are water vapor, which causes about 36 to 70 percent of the greenhouse effect on Earth (not including clouds); carbon dioxide, which causes between 9 to 26 percent; and ozone, which causes between 3 to 7 percent. Minor greenhouse gases include, but are not limited to: methane, nitrous oxide, sulfur hexafluoride, and chlorofluorocarbons.
Ground-truthing	Visiting sites to confirm the accuracy of remotely sensed information.
Groundwater	Water that occurs below the surface of the Earth, where it occupies spaces in soils or geologic strata.
H:h	A waste disposal site with a low to medium hazard rating.
H:V	The ratio of horizontal length (H) to vertical length (V) for a specific slope.
Habitat	An area with generally uniform environmental conditions for a species.
Habitat insularity	Degree of isolation of a habitat patch from other similar habitat patches.
Hardness	Measure of the sum of calcium and magnesium concentrations, expressed as milligrams per liter (mg/L) equivalent of calcium carbonate ($CaCO_3$. Hardness scale consists of very soft (low) (0–30 mg/L $CaCO_3$), soft (31-60 mg/L $CaCO_3$), moderately soft (61-120 mg/L $CaCO_3$), hard (121-180 mg/L $CaCO_3$) and very hard (>180 mg/L $CaCO_3$) waters.
Hazard	A situation with a potential for harm to persons, property or the environment.
Hazard identification	The process of recognizing that a hazard exists and defining its characteristics.

Hazardous materials	Materials released in quantities that may harm persons, property or the environment.
Headwater	The source of a stream or river.
Herpetofauna	Reptiles and amphibians.
HIV	Human immunodeficiency virus; a retrovirus which causes acquired immune deficiency syndrome (AIDS).
Holoendemics	A living organism which has a specialized habitat and therefore has a distribution restricted to a small area.
Holotype	A single specimen designated the type specimen by the original author at the time of publication of the original description.
Homogenous	When the composition of a material is uniform or constant from one point to another.
Horizon	A specific layer of soil or subsoil in a vertical cross section of land. In ABC soil, the uppermost zone of soil, containing humus; topsoil.
Hydraulic units	The concept of the hydraulic (flow) unit was developed to integrate geological and hydrologic data. Hydraulic unit is defined as a group of reservoir rocks with similar properties that affect flowing fluids like water.
Hydromorphic	Relating to soil in a wet environment; relating to or typical of a soil that has built up in the presence of excess water.
Hydrophilic grasses	Grasses requiring large amounts of water.
Hydrophytic plants	A plant adapted for growth in waterlogged soils or areas with regular water source.
Hypereutrophic	One of the four trophic state categories, the hypereutrophic state is defined as having the highest level of biological productivity. The prefix "hyper" means over abundant. Hypereutrophic waterbodies are among the most biologically productive in the world.

Hypolimnion	The lower and colder layer in a lake. The hypolimnion is the bottom and most dense layer of water in a thermally-stratified lake. It is the layer that lies below the thermocline. Typically, it is non-circulatory and remains cold throughout the year.
Iconography	The study of images.
Igneous activity	Activity relating to rocks solidified from molten magma at or above the surface of the earth.
Impervious	Incapable of being penetrated, for example by water.
In situ	In place; the original location; in the natural environment.
Inbreeding depression	Reduced fitness in a given population as a result of breeding of related individuals.
Incipient speciation	The beginning of the formation of a new species.
Infiltration	Movement of water from the land surface into the soil.
Ingestion	To take (food or drink) into the body by swallowing or absorbing it.
Inhalation	To breathe in (air, gas, smoke, etc.).
Inselberg	An isolated rocky hill rising abruptly from a flat plain.
Instream	The amount of water passing a particular point in a stream or river, usually expressed in cubic meters per second (m^3/s).
Insularity	Isolation of a species.
Iron Age	The stage in the development of any people where the use of iron implements as tools and weapons is prominent. In Africa the Iron Age began about 1,400 BC.
Kaolisols	A soil type in the old Zaire soil classification. There is a close similarity of Kaolisols with Ferrisols (United Nations Food and Agriculture Organization [FAO] Classification) or Oxisols (United States Department of Agriculture [USDA] Classification).
Kapita	Chief of a hamlet, of a lower grade than a village chief or a land chief.

K_d	The distribution coefficient or partition coefficient, which is a measure of the affinity of a chemical to partition between the dissolved and particulate phase.
Key indicator species	Biological indicator species are unique environmental indicators as they offer a signal of the biological condition in an ecosystem. Using those bioindicators as an early warning of pollution or degradation in an ecosystem can help sustain critical resources. Key indicator species are actually groups or types of biological resources that can be used to assess environmental condition.
Key question	A specific question defined to assess an issue of specific concern to stakeholders. Used to focus the ESIA and ensure that it clearly addresses the issues of concern.
Kimbalama	Second (mid-rainy season) crop, usually beans.
Kinkurimba	A mutual assistance system in which there is a rotational system of sharing agriculture labor.
Kinyanga	Marshland crops (cultures maraíchéres).
Koppie	A small isolated hill within the African veld.
Landscape character	The individual elements that make up the landscape, including prominent or eye-catching features such as hills, valleys, savannah, trees, waterbodies, buildings and roads. They are generally quantifiable and can be easily described.
Landscape quality	Quality of landscape based on its aesthetic appeal, including topographic ruggedness and relief, water forms, color in the landscape, diverse patterns of grasslands and trees, scarcity of landscape, naturalness of landscape and land use.
Landscape effect (impact)	Landscape effects derive from changes in the physical landscape, which may give rise to changes in its character and how this is experienced.
Laterites	A group of minerals derived from weathering of an ultrabasic type of rock. Encompasses the entire geologic profile from surface to bedrock.
Latrines	A receptacle (as a pit in the earth) for use as a toilet or a communal toilet of a type often used in a camp or barracks.

L_d	The daytime equivalent sound level L_{eq} noise level detected from 7:00 a.m. to 10:00 p.m.
L_{dn}	The noise level detected for a reference period during daytime and nighttime hours. The day/night sound level is a fraction of the day versus nighttime hours to get one value.
Leaching	A chemical process for the extraction of valuable minerals from ore; also, a natural process by which ground waters dissolve minerals, thus leaving the rock with a smaller proportion of some of the minerals than it contained originally.
Legume	A member of the pea family (Fabaceae); a dry dehiscent fruit derived from a single carpel and usually splitting along two lines.
L_{eq}	Equivalent sound level. A sound level that, if constant over a referenced time period, would contain the same amount of sound energy as the actual sound which varied in level within that time.
Life form	An individual form of life, such as a plant, animal, bacterium, protist, or fungus; a body made up of organs, organelles, or other parts that work together to carry on the various processes of life.
Limnology	The study of bodies of fresh water with reference to their plant and animal life, physical properties, geographical features, etc.
Linkage diagram	A diagram linking project activities, environmental changes, key questions and other discipline areas to assist specialists in their work and to enable readers to understand what has (and has not) been included in the impact analysis.
Listed species	Species (plants or animals) listed by international organizations as having special status due to their rarity. See ‘endangered’.
Lithology	The study of the mineral content, grain size, texture and color of rocks.
L_{max}	The highest noise level detected over a referenced period of time.

L_{min}	The lowest noise level detected over a referenced period of time.
L_n	The nighttime equivalent sound level L_{eq} noise level detected from 10:00 p.m. to 7:00 a.m.
Logistic	The science of planning and implementing the acquisition and use of the resources necessary to sustain the operation of a system.
Lotic ecosystems	Natural communities living in rapidly moving water.
Lower risk	Based on World Conservation Union (IUCN) criteria, a taxon is Lower Risk when it has been evaluated, does not satisfy the criteria for any of the categories Critically Endangered, Endangered or Vulnerable. Taxa included in the Lower Risk category can be separated into three subcategories.
L_{peak}	The peak noise level detected over a referenced period of time.
Macroinvertebrate	An invertebrate animal (animal without a backbone) large enough to be seen without magnification.
Magnitude	Degree of change to analysis endpoint.
Malachite	A green copper carbonate mineral.
Mannings equation	A standard hydraulic equation to calculate flows and flow depths.
Mantle	The outer soil layers that covers the terrain.
MAP (Mean annual precipitation)	The average amount of precipitation that is recorded in a year. Precipitation is recorded as a depth and is usually expressed in millimeters. Precipitation includes rainfall, snowfall, hail, mist, dew and fog. Snow does not normally occur in the concession area.
Mbile	A mutual assistance system in which people are invited to help with agriculture labor in exchange for food and drinks.

MDL (Method detection limit)	The lowest concentration at which individual measurement results for a specific analyzed are statistically different from a blank (that may be zero) with a specified confidence level for a given method and representative matrix.
Meka	Standard measure for cereals, beans and other agriculture products. Weighs approximately 2.6 to 2.8 kilograms.
Mensuration	The act or process of measuring.
Meq/100 g	Milliequivalents of exchangeable ions retained by 100 grams of soil. Cation exchange capacity is sometimes expressed in terms of meq/100 g of soil. The unit meq/100 g is equal to cmol kg^{-1}.
Mesotrophic	A moderate nutrient-rich status.
Metallicolous ecosystems	A singular ecological system that functions upon terrain (rocks or soil) that has high metals content.
Metalliferous soil	Soil with high concentrations of heavy metals with very restrictive habitats for plants and are limited in size and geography.
Metallophytes	Species that only occur on metal-rich soils.
Meteorology	The study or science of the atmospheric character of a region.
Microevolution	Minor change in a small group of organisms or species.
Miombo	A vernacular word that has been adopted by ecologists to describe those woodland ecosystems dominated by trees in the genera *Brachystegia*, *Julbernardia* and *Isoberlinia* of the family *Fabacea.*
Miombo woodland	A type of deciduous woodland which covers a vast area of southern Africa.
Mitigation	All actions aimed at reducing the extent or likelihood of pollution or environmental impacts, as well as actions aimed at reducing their negative effects. To cause to become less harsh or hostile.
Mitigation measures	All actions aimed at reducing the extent or likelihood of pollution or environmental impacts, as well as actions aimed at reducing their negative effects.

Monera	Unicellular and colonial including the true bacteria (eubacteria) and cyanobacteria (blue-green algae).
Mulch/Mulching	A protective covering, usually of organic matter such as leaves, straw, or peat, placed around plants to prevent the evaporation of moisture, the freezing of roots, and the growth of weeds. Mulching is covering or surrounding with mulch.
Mutual Aid Agreement	An agreement among two or more public or private organizations or operations to provide emergency-related assistance to each other.
Mutualism	Two species living together in a relationship in which both benefit from the association.
Mycorrhizal fungi	A type of fungus, which is often applied to the roots of a vine at planting. The mycorrhizae forms a mutually beneficial relationship with the plant's roots. As such it acts as an extension of the root system, increasing the roots' ability to absorb nutrients and water. Some research indicates that the co-dependent symbiotic relationship between the fungi and the vine helps the vine to survive stress, absorb more water and nutrients, and increase its resistance to soilborne diseases.
Neoendemics	A species with a restricted distribution as a result of more recent events (recent on a geological time scale) and which has not had time to colonize several sites.
Noise	"Noise" or "noise levels" refers to the levels that can be heard or measured at a receiver.
Noise level	Noise levels and sound emissions also have a "frequency". The human ear does not respond to all frequencies in the same way. Mid-range frequencies are most readily detected by the human ear, while low and high frequencies are harder to hear. Environmental noise levels are usually presented as "A-weighted" decibels (or dBA), which incorporates the frequency response of the human ear. While low-frequency noise may not be "heard", it can often be felt.
Noise receiver	A noise "receiver" is a location where measurements or predictions of noise levels are made.
Non-timber forest products	Goods derived from forests of both plant and animal origin other than timber and firewood.

Nutrients	Environmental substances (elements or compounds) such as nitrogen or phosphorus, which are necessary for the growth and development of plants and animals.
OHSA	Occupational Health and Safety Assessment Series (ISO 18,000) which define an Occupational Health and Safety Management System.
Oligotrophic	Trophic state classification for lakes characterized by low productivity and low nutrient inputs (particularly total phosphorus).
Open cast (open pit) mining	A method of extracting rock or minerals from the earth by their removal from an open pit or borrows. The term is used to differentiate this form of mining from extractive methods that require tunneling into the earth.
Open pit	A mine that is entirely on surface. Also referred to as open-cut or open-cast mine.
Operation	A process, including but not limited to, transportation, manufacturing, storage, distribution, use, or disposal.
Ore	A mixture of ore minerals and gangue (valueless and undesireable material, such as quartz in small quantities, in an ore) from which at least one of the ore minerals can be extracted at a profit or that is economically feasible for mining.
Ore body	A natural concentration of a valuable mineral or minerals that can be extracted and sold at a profit.
Organic carbon	The most abundant element found in all organisms. In aquatic environments, organic carbon is produced by plant photosynthesis and bacterial growth. Leaching of humic substances and decomposition of plants and animals are also natural sources of organic carbon to surface waters.
Organic matter	Compounds containing carbon often derived from living organisms. As well, the part of the soil that includes the decomposing remains of plants and animals, as well as the product of complete decomposition, known as humus.

Organic nitrogen	Any nitrogen compound produced by natural (that is, living things) rather than synthetic (or man-made) processes. It is the nitrogen combined in organic molecules such as proteins, amines, and amino acids and other organic nitrogen substances produced by organisms in the soil.
Outdoor Noise	Usually expressed as an "equivalent noise level" (L_{eq}), which is a logarithmic average of the measured or predicted noise levels over a given period of time. This type of average takes into account the natural variability of sound.
Overburden	Rock or soil overlying a mineral deposit.
Overtopping	The flow of water over the top of a dam or embankment. Also, the vegetation higher than the favoured species, as in brush or deciduous species that are shading and suppressing more desirable coniferous trees.
Oxisols	A United States Department of Agriculture (USDA) soil type consisting of soils with a B horizon in which most weatherable materials have been removed leaving oxides of iron and aluminum and some quartz.
Palaeoendemics	A species with restricted distribution which may have had a large distribution at one time (not recent on a geological time scale) but presently exists only in a few places or in one place.
Palaeractic	Biogeographic region that includes Europe, the northwest coast of Africa and northern Asia.
Pan evaporation	Evaporation measured using a pan of water, where water evaporates from the water surface.
Pan wetland/pans	Seasonally saturated wetlands.
Partition coefficients	Describes the partitioning of a chemical between sorbing material such as surface water, suspended solids and sediments.
Pedogenesis	The formation of soils through the natural process of soil erosion and leaching.
Pedon	The smallest volume (soil body) which displays the normal range of variation in properties in soil.

Periphyton	Organisms (as some algae) that live attached to underwater surfaces.
Permeability	Capacity of a soil or other surface to be penetrated by water sinking into the ground under the force of gravity. It thus expresses the rate of percolation. Also, the ability of a material to allow the passage of a liquid, such as water through rocks. Permeable materials, such as gravel and sand, allow water to move quickly through them, whereas unpermeable materials, such as clay, do not allow water to flow freely.
pH	The negative logarithm of the hydrogen ion activity, pH is an indication of the acidic or basic, i.e., alkaline, nature of water. Neutral water has a pH of seven. The potential hydrogen scale, measuring the acidity or alkalinity of a solution, from zero (highly acidic) to 14 (highly alkaline).
Phenology	The study of how plants species are influenced by environmental factors such as climate.
Phosphorus	The key nutrient influencing plant growth in lakes; total phosphorus includes the amount of phosphorus in solution (reactive) and in particulate form.
Physiognomic	The description of the number and cover types of plant formations among different strata.
Physiognomy	The outward physical appearance of a species. A person's facial features or expression, especially when regarded as indicative of character or ethnic origin.
Phytogeochemistry	The study of metabolic and chemical processes in plants.
Phytogeographic	The location or biogeography of a plant species.
Phytoremediation	The use of plants to remove contaminants or chemicals in the soil by the accumulation of the contaminant by the plant.
Phytosociology	The study of the organization, development, geographical distribution and classification of plant communities.
Phytotoxic	Toxic or poisonous to plants.
Phytotoxicity	The level of toxicity to a substance in a plant.

Piche evaporation	Evaporation measured using an anemometer, where water evaporates from a filter paper at the open end of a water-filled glass tube.
Piedmont	An area of land formed or lying at the foot of a mountain or mountain range.
Pisolites	Soils containing gravel-like concretions.
Pit lake	Artificial lakes made deliberately by digging, or by flooding an open-pit mine.
Plume	Visible or measurable discharge of a contaminant from a given point of origin; it can be visible or thermal in water or visible in the air as, for example, a plume of smoke.
PLUMES	Mathematical model for dilution modeling.
PM_{10}	Airborne particulate matter with mean diameter less than 10 μm (microns) in diameter.
$PM_{2.5}$	Airborne particulate matter with mean diameter less than 2.5 μm (microns) in diameter.
PMR (Plant Micro-Reserve)	Small plots of land of peak value in terms of plant species richness, endemism (locally on regionally occurring) or rarity, given over to long-term monitoring and conservation of plant species and vegetation types. PMRs are designed to conserve vegetation and to develop or test active conservation methods that bring together ex situ and in situ actions.
Potable	Refers to drinkable. Water that is potable is clean and free from harmful chemicals and disease-carrying microbes.
Potential evaporation	The amount of water that will be evaporated if this water is available. Evaporation is usually recorded as a depth and expressed in millimeters.
Prevention	Activities and programs designed to eliminate hazards before they can become emergencies.
Process water	Water that serves in any level of the manufacturing process of certain products or the water used in the scheduled depuration process.
Profanation	The act of depriving something of its sacred character.

Propagation	The act of multiplication by a plant or animal by any process of natural reproduction from the parent stock. It is a method of increasing the number of plants by dividing roots, layering or start from cuttings.
Protista	Unicellular protozoans and unicellular and multicellular (macroscopic) algae.
Protohistoric	The transition period between oral tradition and written history in a society. This also refers to the period during which a society of primarily oral tradition begins to feel the influence of a contact with a society of writing. In Africa, the protohistoric period is regarded as the leading into the Iron Age between 1,400 B.C. and A.D. 200. In some areas, Protohistoric also refers to the time of initial contact before European colonization.
QA/QC (Quality Assurance/Quality Control)	A set of practices that ensure the quality of a product or a result. For example, "Good Laboratory Practice" is part of QA/QC in analytical laboratories and involves such things as proper instrument calibration, meticulous glassware cleaning and an accurate sample information system.
Ramsar site	Wetlands of recognized international importance, which have been designated for protection and "wise use" under the Ramsar convention of 1971 based on their significance in terms of ecology, botany, zoology, limnology or hydrology.
Rare	Not frequent; seldom occurring or scarce.
Rating curve	A relationship between flow and water depth for a particular section of river.
Reach (Stream)	A reach in geography is an expanse, or widening, of a stream or river channel. This commonly occurs after the river or stream is dammed.
Receptor	A point or location where the existing activity may be adversely affected when noise levels exceed predefined thresholds of acceptability or when levels increase by predefined thresholds of change.
Recharge	Addition of water (percolation) that reaches the zone of saturation (groundwater). Also used to refer to the volume of water reaching the zone of saturation.

Reclamation	The restoration of a site after mining or exploration activity is completed.
Red-listed	Species on the World Conservation Union/International Union for the Conservation of Nature (IUCN) Red List due to some level of threat.
Reserve	That part of a mineral resource that can be mined profitably.
Resources	In emergencies,resources are the personnel, equipment, and information required to respond effectively to an emergency.
Response	Activities designed to address the immediate and short-term effects of an emergency.
Reversibility	Effect on the resource (or resource capability) can or cannot be reversed.
Riffles	A reach of stream that is characterized by shallow, fast-moving water broken by the presence of rocks and boulders.
Riparian	Relating to or living or located on the bank of a natural watercourse (as a river) or sometimes of a lake or a tidewater. Refers to terrain, vegetation or simply a position next to or associated with a stream, flood plain, or standing waterbody.
Riparian forest	Forest that occurs within a riparian zone, along watercourses or waterbodies. See also gallery forest.
Risk	A measure of the likelihood and the consequence severity with a hazard occurring.
River reaches	A comparatively short length of river, stream channel or shore within which habitat conditions are similar.
Royalty	An amount of money paid at regular intervals by the lessee or operator of a mining property to a lender or the owner of the ground. Generally based on a certain amount per tonne or a percentage of the total production or profits.

Runoff	The water from rain, snowmelt or irrigation that flows over the land surface and is not absorbed into the ground, instead flowing into streams or other surface waters or land depressions.
Rupicolous	Thriving or living among small rocks.
Sacred character	The quality of being holy; devoted to a deity or spirit. Having some religious ceremonial use or supernatural function in ritual.
SAG Mill	Semi-autogenous grinding mill. A SAG mill is used for crushing ore. It rotates, tumbling its contents violently, causing a breaking action. The mill is lined with wear-resistant steel liners. Fresh ore is continually conveyed into the mill feed chute and is crushed by means of steel balls until small enough to pass though the openings in the discharge grates.
Savanna	Flat grassland of tropical or subtropical regions.
Saxicolous	Growing on, or living among, rocks.
Sclerophyll	Woody plant with leathery leaves: any woody plant of arid areas with thick leathery evergreen foliage that retains water.
Seasonal wetlands	Wetland area that is only wet seasonally.
Secchi disk	A circular plate, generally about 10-12 inches (25.4-30.5 centimeters) in diameter, divided into black and white quarters, used to measure the transparency or clarity of water by noting the greatest depth at which it can be visually detected. Its primary use is in the study of lakes.
Second order stream	A stream in which many first order streams join to make a second order stream.
Sedimentation	Deposition of organic or inorganic material (sediment) that is transported and deposited by wind and water.
Seismic	An interpretation of geologic strata through measurement and recording of sound wave transmission below the surface produced by earthquakes, seaquakes, volcanoes and tectonic plates or by equipment or methods used to create Earth vibrations, such as exploding dynamite in oil exploration.

Sense of place	The unique value that is allocated to a specific place or area through the cognitive experience of the user or viewer.
Sensitive areas	Environments or ecosystems considered sensitive under Democratic Republic of the Congo (DRC) regulations (Annex XII). These include marshes, lakes, areas were threatened plant or animal species live, areas subject to erosion, and sources of potable water.
Sensitive receptors	Visual receptors (viewers) potentially sensitive to the proposed development.
Serpentine	A rock mineral group with the general formula $(MgFe)_3Si_2O_5(OH)_4$.
Silt	Fine particles of sand or rock that can be picked up by the air or water and deposited as sediment.
Soil aggregate	A unit of soil structure consisting of primary soil particles held together by cohesive forces or by secondary soil materials such as iron oxides, silica or organic matter.
Sound	"Sound" or "sound emissions" refers to the acoustic energy generated by natural or man-made sources, including the project activities.
Sound Volume	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 sound or noise with double the number of decibels is much more than twice as loud. A change of three decibels is also the general threshold at which a person can notice a change in sound volume.
Speciation	The formation of a new species.
Species area curve	A graph that shows the cumulative number of plant species encountered as the area surveyed increases.
Species of concern	An informal term for a plant or animal with declining populations and believed in need of concentrated conservation actions such as research, monitoring, or removal of threats, and given legal classification as threatened or endangered.

SRDT (Solar radiation/delta-T)	Method to measure solar radiation from the United States Environmental Protection Agency (US EPA).
Steppic plant communities	Steppe is an open vegetation unit (the grass layer does not cover 100 percent of the surface) with the dominance of two biological types namely cespitose (tuffed) herbs (mainly grasses and sedges) but also geofrutex (= Magnoliopsida = dicotyledons plants with a woody underground organ).
Stockpile	Broken ore heaped on the surface, pending treatment or shipment.
Stoloniferous	Producing stolons, a horizontal branch from the base of a plant, trailing over the soil surface and rooting at the apex or the nodes.
Stone Age	The stage in the development of any people where the use of stone implements as tools and weapons is prominent. In Africa, the Stone Age begins about 2 million years ago and extends to about 3,000 B.C. when the use of naturally occurring metals, such as copper, begins.
Storativity	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer, per unit change in head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equal to the specific yield.
Storm water	Precipitation that accumulates in natural and/or constructed storage and stormwater systems during and immediately following a storm event and that is often routed into drain systems in order to prevent flooding.
Stressors	Pressure or tension exerted on a material object.
Strip	To remove the overburden or waste rock overlying an ore body in preparation for mining by open-pit methods.
Strip mining	A process that uses machines to scrape soils or rock away from mineral deposits just under the earths's surface.
Stripping ratio	The ratio of tonnes removed as waste to the number of tonnes of ore removed from an open-pit mine.
Subsistence fishery	A fishery in which the fish caught are consumed directly by the families of the fishers rather than being bought by middle-men and sold at the next larger market.

Supernatant	The liquid, containing soluble compounds, which is left behind after a mixture is centrifuged or precipitated. The liquid lying above a solid residue after crystallization, centrifugation, or other process.
Surface miner	A track-mounted machine with a large rotating drum with hardened steel picks used to break up ore in situ.
Surface water	Water standing on the top of ground or soil, waiting either to soak down into the soil or to evaporate. Is also used to characterize water that collects and stands or is stored in lakes, ponds, rivers, bayous, streams, canals and reservoirs, either natural or man-made.
Suspended sediments	Particles of matter suspended in the water. Measured as the oven dry weight of the solids, in milligrams per liter (mg/L), after filtration through a standard filter paper. Less than 25 mg/L would be considered clean water, while an extremely muddy river might have 200 mg/L of suspended sediments.
Sustainable development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
Swidden agriculture	Agricultural technique whereby forest vegetation is cut down, let dry and burned to prepare fields for crops and fields that are not cultivated continuously.
Syncline	Basin or trough-shaped fold in the rock in which rock layers are downwardly convex. The youngest rock form the core of the fold and outward from the core progressively older rocks occur.
Tailings	Material rejected from a mill after most of the recoverable valuable minerals have been extracted. Also, residues separated in the preparation of various products (as grain or ores).
Tailings pond	A depression used to confine tailings.
Tainting	A contaminating influence or effect with a bad or undesirable quality.
Taxa	Groupings of organisms based on their formal taxonomic names such as species, genus or family groups.

TDS (Total dissolved solids)	The total concentration of all dissolved compounds solids found in a water sample.
Tectonic activity	Movements of the Earth's crust such as earthquakes, folds and faults.
Temporal	Of or relating to or limited by time as temporal processing, temporal dimensions and temporal and spacial boundaries.
Termitaria	Nests built by colonies of termites.
Third order stream	A third order stream has only first and second order tributaries.
Tilth	The physical condition of the soil as related to its ease of tillage, fitness as a seedbed, and impedence to seedling emergence and root penetration. Good tilth is a sign of healthy soil organisms. While digesting organic material, bacteria secrete gum and slime-like matter in the soil. This works like glue, binding soil particles and humus together to form aggregates.
Ton	2,000 pounds.
Tonne	Metric ton, 1,000 kilograms.
Total soil nitrogen	Sum of organic and inorganic nitrogen in a defined soil sample.
Toxicity	A measure of the quality or state of being poisonous.
Trabeco	Tranverses en Béton du Congo: a concrete railways sleepers factory that was formerly based in Fungurume.
Transhumance migration	The seasonal migration of farmers to suitable farming lands.
Transhumance agriculture	The practice of living in one area for part of the year and farming and living in another area for the other part of the year.
Translocation	Movement of nutrients or other substances within an organism. As well, it is the movement of native or introduced species to habitats outside their natural or previous distribution; endangered species are now translocated by humans in efforts to preserve them from extinction.

Transmissivity	The rate at which groundwater can flow through an aquifer section of unit width under a unit hydraulic gradient. It is the average permeability of a section of the entire aquifer at a given location multiplied by the thickness of the formation.
Transplantation	To uproot and replant a growing plant to a new location.
TRV (Toxicity reference value)	A quantitative expression that benchmarks the potency of each substance.
TSP (Total suspended particulates)	Particles which includes airborne particulates nominally smaller than 30 microns (μm) in aerodynamic diameter.
TSS (Total suspended solids)	Solids, found in wastewater or in a stream, which can be removed by filtration. The origin of suspended matter may be artificial or anthropogenic (man-made) wastes or natural sources such as silt.
Tufa	A soft porous rock consisting of calcium carbonate deposited from springs or creeks rich in lime.
Turbidity	Turbidity is cloudiness or opacity in the appearance of a liquid caused by solids, particles and other pollutants. Turbidity measurement provides an indication of the clarity of water and water quality.
Understorey	Those trees or other vegetation in a forest stand below the main canopy level.
Uplands	Areas where the soil is not saturated for extended periods as indicated by vegetation and soils.
Vegetation unit	A patch, grouping or zone of plants evident in overall plant cover, which appears distinct from other such units because of the vegetation's structure and floristic composition; a given unit is typically topographically distinct and typically has a rather uniform soil.
Viewshed	The two-dimensional spatial pattern created by an analysis that defines areas, which contain all possible observation sites from which an object would be visible. Area of land seen from a single viewpoint or from a series of viewpoints such as along a highway or waterway.
Visibility	The area/points where project components are potentially visible.

Visual aesthetics	The quality of the visible environment.
Visual effects (impact)	Visual effects relate to the changes that arise in the composition of available views as a result of changes to the landscape, to people's responses to the changes, and to the overall effects with respect to visual amenity.
Visual exposure	Visibility and visual intrusion qualified with a distance rating to indicate the degree of intrusion.
Visual intrusion	The nature of intrusion of an object on the visual quality of the environment resulting in its compatibility (absorbed into the landscape elements) or discord (contrasts with the landscape elements) with the landscape and surrounding land uses.
Visual receptors	Visual receptors (viewers) potentially sensitive to the proposed development.
Visual resource	Aesthetic value or scenic beauty is the rating given to a particular landscape. It is the emotional response derived from the experience of the environment with its particular natural and cultural attributes. The response can be either to visual or non-visual elements and can embrace sound, smell and any other factor having a strong impact on human thoughts, feelings and attitudes. Thus aesthetic value encompasses more than the seen view, visual quality or scenery, and includes atmosphere, landscape character and sense of place and is collectively described as the visual resource.
Vleis	Seasonal wetlands.
VOC (Volatile organic compounds)	Gaseous hydrocarbons that exclude methane, and tend to contribute to chemical reactions in the atmosphere.
Vulnerable	A species is vulnerable by World Conservation Union/International Union for Conservation of Nature (IUCN) definition when the best available evidence indicates that it faces a high risk of extinction in the wild.
Waste	Unmineralized, or sometimes mineralized, rock that is not mineable at a profit.
Watershed	The specific land area that drains water into a river system or to a particular point along a stream. Each stream has its own watershed.

Wetland	An area that is regularly saturated by surface water or groundwater and is characterized by a prevalence of vegetation that is adapted for life in saturated soil conditions (e.g., swamps bogs, fens, marshes, and estuaries).
Windrose	A type of figure often used to illustrate the frequency of wind direction and the magnitude of the wind velocity. The lengths of the bars on the windrose indicate the frequency and speed of wind. The direction from which the wind blows is illustrated by the orientation of the bar in one of 16 cardinal directions.
Worked stones	Stones that have been shaped or modified by a human to form a tool or other object.
Zone of potential influence	The area defined as the radius about an object beyond which the visual impact of its most visible features fade into the background and become insignificant in the greater landscape scene.

ACRONYMS AND ABBREVIATIONS

SAWMS-1998	1998 South African Waste Management Series
OSHA	US Occupational Safety and Health Administration
EHS Guidelines	Environmental, Health and Safety Guidelines
%	Percent
<	Less than
>	More than
°C	Temperature in degrees Celsius
µeq/L	Microequivalent per liter
µg/Kg	Microgram per kilogram
µg/L	Microgram per liter
µL	Microliter
µm	Micron
µPa	Micro Pascal
µS	Micro Siemens
$\mu S/cm^2$	Micro Siemens per square centimeter
µS/h	Micro Siemens per hour
AA	Atomic absorption
ABA	Acid-base accounting
ACRU	Agricultural Catchments Research Unit
ADFL	Alliance of Democratic Forces for the Liberation of Congo-Zaire
Ag	Silver
AGC	Australian Groundwater Consultants
AGP	Acid generating potential
AIDS	Acquired immune deficiency syndrome
Al	Aluminum
Al_2O_3	Aluminum oxide
ALBA	Association Laique pour les Bambins d'Afrique (Secular Association for The African Children)
AM	Audio monitoring
ANC	Acid neutralizing capacity
ANFO	Ammonium nitrate / fuel oil

ANP	Acid neutralizing potential
ANR	Agence National de Renseignement
ANSI	American National Standards Institute
AP	Acid generation potential
ARD	Acid rock drainage
ARMC	Amended and restated mining convention
Art.	Article
As	Arsenic
ASME	American Society of Mechanical Engineers
atm	Atmospheres
Au	Gold
B	Boron
Ba	Barium
BBC	British Broadcasting Corporation
BCF	Bioconcentration factors
BDD	Bureau Diocesan Pour le Development (Diocesan Bureau for the Development)
Bi	Bismuth
BID	Background information document
BMP	Best management practices
BOD	Biological oxygen demand
BOD_5	Biochemical oxygen demand
BPF	Barely perceptible flow
BPIP	Building Profile Input Program
Bq	Becquerel
Br	Bromide
BR	Belgian National Botanic Garden at Meise
BRGM	Bureau des Recherchés Géologiques et Minières (Geological and Mining Surveys Agency)
BRLU	Laboratoire de Botanique systématique of the Brussels Free University
C	Carbon
ca	Circa
Ca	Calcium

$CaCl_2$	Calcium chloride
$CaCO_3$	Calcium carbonate
CadnaA	Computer aided noise abatement model
$CaMgHCO_3$	Calcium magnesium bicarbonate
CAMP	Conservation assessment and management planning
CaNP	Carbonate neutralization potential
CARPE	Central African Program for the Environment
CBD	Convention on Biological Biodiversity
CCC	Criterion continuous concentration
CCD	Countercurrent decantation
CCISR	Center of Catchment and In-Stream Research
CCME	Canadian Council of Ministers of the Environment
Cd	Cadmium
CD	Chart Datum
CDA	Canadian Dam Association
CDAP	Community development action plan
CDC	Community Development Committee
CdG	Chef de Groupement, Chief of Groups
CDH	Human Rights Center
CdT	Chef de Terre, Land Chief
CEA	Cumulative effects assessment
CEC	Cation exchange capacity
CEMI	Canadian Environment Metallurgic Inc.
CFU	Colony forming units
CFU/100 ml	Colony Forming Units per 100 milliliters
CH	Cultural heritage
CI	Conservation International
CIA	Central Intelligence Agency
CITES	Convention on International Trade in Endangered Species
Cl	Chlorine
CLE	Critical level
CLO	Community liaison officer
cm	Centimeter

CM	Corrective maintenance
CMC	Criteria maximum concentration
CMN	Calcaire a mineral noir (siliceous dolomite and graphitic shale)
cmol	Centimole – charge of saturating ion per kilogram
Co	Cobalt
CO	Carbon monoxide
CO_2	Carbon dioxide
COC	Chemical (or constituent) of concern
COMIFAC	Central African Forests Commission
COPC	Chemicals of potential concern
CPC	Center of Plant Conservation
CPESC	Certified professional in erosion and sediment control
CPR	Cardiopulmonary resuscitation
CPUE	Catch per unit of effort
CPWCC	Canadian Pipeline Water Crossing Committee
Cr	Chromium
CSIR	Center for Scientific and Industrial Research of South Africa
CTB	Coopération Technique Belge (Belgian Technical Cooperation)
CTE	Technical evaluation committee
Cu	Copper
CVAA	Cold vapor atomic adsorption
CVDNN	Coefficient of variation in distance to nearest neighbor
CZMW	Central Zambezian Miombo Woodland
d	Day
dBA	A-weighted decibels
DBH	Diameter at breast height
dBL	Linear decibels
DCA	Direct concession area (Initial planned project footprint)
DEM	Digital elevation model
DFID	UK Department for International Development
DFO	Department of Fisheries and Oceans (Canada)

DL	Detection limit
DO	Dissolved oxygen
DOE	Department of environment
DRC	Democratic Republic of the Congo
DSHA	Deterministic seismic hazard assessment
DW	Dry weight
E	East
E. coli	Escherichia coli
e.g.	For example
EA	Environmental assessment
EC	Electrical conductivity
EC_{20}	Effects Concentration (EC) is the concentration that results in a decrease of 20 percent of the measured variables
EC_{50}	Effects Concentration (EC) is the concentration that results in a decrease of 50 percent of the measured variables
ECI	Environmentally conservative isotherms
ECRP	Emergency and contingency response plan
EDS	Environmental design standard
EEM	Environmental effects monitoring
EFMA	European Fertilizer Manufacturers Association
Eh	Redox potential
EIA	Environmental impact assessment
EIE	Environmental impact effect
EIFAC	European Inland Fisheries Advisory Commission
EMNN	Euclidean mean distance to nearest neighbor
EMP	Environmental management plan
EMS	Environmental management system
ENSO	El Nino southern oscillation
EOP	Emergency operation plan
EP	Equator principles
EPC	Engineering procurement and construction
ERP	Emergency response plan
ERT	Emergency response team

ESA	European Sulfuric Acid Association
ESIA	Environmental and social impact assessment
ESMS	Environmental and social management system
et al	And others
EU	European Union
EV	Extreme value
F	Fluorine
FAM	Fe-Al-Mn (Iron, aluminum and manganese)
FAO	United Nations Food and Agriculture Organization
Fc	Franc congolais, Congolese francs
Fe	Iron
Fe/Al/Mn	Iron / aluminum / manganese (see FAM)
FeOOH	Iron oxide-hydroxide
FIDIC	International Federation of Consulting Engineers
FS	Feasibility study
FY	Fiscal year
g	Gram
g/L	Gallon per liter
GC	Geochemical controls
GDP	Gross domestic product
GDRC	Government of the Democratic Republic of the Congo
Gécamines	La Générale des Carriéres et des Mines
GEPFE	Groupe d'Études des Populations Forestières Équatoriales
GHG	Greenhouse gases
GIS	Geographic information system
Golder	Golder Associates Ltd.
GP	Good practice
GPS	Global positioning system
GRI	Global reporting initiative
H&S	Health and safety
ha	Hectare
Hazen	Hazen Research Inc.
HAZID	Hazard identification study

HCO_3	Bicarbonate
HDPE	High-density polyethylene
Hg	Mercury
HG	High grade
HG PLS	High-grade pregnant leach solution
HIV	Human immunodeficiency virus
H_{max}	Maximum wave height
hr	Hour
HRDP	Human resource development plan
HSMS	Health and safety management system
HSP	Health and safety plan
Hz	Hertz (Unit of frequency)
I&APs	Interested and affected parties
i.e.	That is
ICCN	Institut Congolais pour la Conservation de la Nature (Congolese Institute for the Natural Conservancy)
ICOLD	International Commission on Large Dams
ICP	Inductively coupled plasma
ICP-MS	Inductively coupled plasma mass spectrometry
IDF	Inflow design flood
IDFC	Intensity-duration-frequency curve
IFC	International Finance Corporation
IFESH	International Foundation for Education and Self-help
IHIA	Intermediate habitat integrity assessment
ILCR	Incremental lifetime cancer risk
INDVAL	Indicator value method
IP	Internal paging
IPPC	Integrated pollution prevention and control directive
Ir	Iridium
ISCST3	Industrial Source Complex Short-term Model
ISO	International Organization for Standardization
ISQG	Interim sediment quality guideline
ISRIC	International Soil Reference Information Center

ITN	Insecticide treated nets
IUCN	International Union for the Conservation of Nature and Natural Resources (Also known as World Conservation Union)
K	Potassium
KCl	Potassium chloride
kg	Kilogram
Kg/ha	Kilogram per hectare
Kg/t	Kilogram per ton
Km	Kilometer
km/h	Kilometers per hour
Km^2	Square kilometers
KRBC	Kew Royal Botanic Gardens
Kt/yr	Kilotonnes per year
L	Liter
L/s	Liter per second
L_{Aeq}	Equivalent sound level
LC	Lethal concentration
LEV	Log extreme value
LG	Low Grade
LGIM	Large mining investment act
LHL	Lundin Holdings Ltd.
LMS	Low magnesium saprolite
LN	Log normal
LNTPB	Laboratoire National des Travaux Publics et du Bâtiment (Public Works and Building National Laboratory)
LOI	Loss in ignition
LOTOTO	Lock/Tag/Try
LSA	Local study area
Ltd.	Limited
LWD	Large woody debris
M	Million
m	Meter
m^2	Square meter

m^3/h	Cubic meters per hectare
m^3/s	Cubic meters per second
MAB	Man and Biosphere Program (UNESCO)
MAC	Mining Association of Canada
mamsl	Meters above mean sea level
MAP	Mean annual precipitation
MAR	Mean annual runoff
masl	Meters above sea level
MB	Mass balance
mbcl	Meters below collard level
MBG	Missouri Botanical Gardens
mbgl	Meters below ground level
MCE	Maximum credible earthquake
MCL	Maximum contaminant level
MDL	Method detection limit
MDNN	Mean distance to nearest neighbor
meq	Milliequivalent
MEW	Mass of evaporated water
MFI	Microfinance institution
Mg	Magnesium
mg	Milligram
mg/kg/d	Milligram per kilogram per day
mg/L	Milligram per liter
mg/m^2	Milligram per square meter
mg/m^3	Milligram per cubic meter
MGW	Mass of groundwater
mL	Milliliter
ML	Metal leaching
mL/yr	Milliliter per year
mm	Millimeter
mm/month	Millimeters per month
mm/s	Millimeters per second
Mn	Manganese

MNOL	Maximum normal operating level
Mo	Molybdenum
MONUC	Mission Observation of United Nations for Congo
MOU	Memorandum of understanding
MPW	Mass of pit lake water
MRD	Maximum daily rate of deposition
MS	Magnitude scale
mS/cm	Millisiemens per centimeter
MSDS	Material safety data sheet
Msed	Mass of bottom sediments
MSF	Médecins sans frontiéres
MSS	Mass of all suspended particle matter
MSW	Mass of surface water
Mt	Metric tons
mtpa	Million tonnes per annum
mv	Mass/volume
mV	Millivolts
MVCLA	Market value chain livelihoods analysis
MWe	Megawatt electrical
n	Number
N	Nitrogen
n/a	Not applicable
na	Not analyzed
Na	Sodium
NAG	Net acid generation
Nb	Niobium
NCDC	National climatic data center
ND	No data
n-day	Number of days
NECSA	Nuclear Energy Corporation of South Africa
NGO	Non-governmental organization
NH_3	Ammonia
Ni	Nickel

nm	Nanometer
NMC	New Mine Code
NNP	Net neutralization potential
NO	Nitrogen monoxide
NO_2	Nitrite / nitrogen dioxide (gas)
NO_3	Nitrate
NOAA	United States National Oceanic and Atmospheric Administration
NO_x	Nitric and nitrous oxides
NP	National park
NPR	Neutralization potential ratio
NRC	National Research Council
NSD	Not sufficient data
NTFP	Non-timber forest products
NTU	Nephelometric turbidity units
O/F	Over flow
OBE	Operating basis earthquake
OECD	Organization for Economic Cooperation and Development
OHSP	Occupational health and safety plan
OJ	Official journal
OMS	World Health Organization (Congo)
ONE	Office National pour l'Environnement (Environmental National Office)
OP	Operational policy
Os	Osmium
P	Phosphorus
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
PCA	Principal component analysis
pCi	Picocurie
pCi/L	Picocuries per liter
PCOC	Potential chemicals of concern
Pd	Palladium

PD	Phelps Dodge Corporation
PEL	Probable effect level
PGA	Peak horizontal ground acceleration
PLS	Pregnant leach solution
PM_{10}	Airborne particulate matter with mean diameter less than 10 µm (microns) in diameter
$PM_{2.5}$	Airborne particulate matter with mean diameter less than 2.5 µm (microns) in diameter
PMF	Probable maximum flood
PMP	Probable maximum precipitation
PMR	Plant micro-reserve
PN	Parc national (National park)
PO_4	Phosphate
PPAH	Pollution prevention and abatement handbook
ppb	Parts per billion
PPE	Personal protective equipment
ppm	Parts per million
PRA	Participatory rural appraisal
PS-1	Pump station 1
PSHA	Probabilistic Seismic Hazard Association
Pt	Platinum
Q&A	Questions and answer session
QA/QC	Quality Assurance/Quality Control
QESF	Qualité de l'Eau de Surface (Surface Water Quality)
RAIS	Risk assessment information system
Ramsar	Convention on wetlands of international importance especially as waterfowl habitat
RAP	Resettlement action plan
RAT	Roche argilleuse talquese (argillic talcose rocks)
RATG	Roche Argilotalesqueuse (brecciated dolomitic and sandy shale)
RDC	Regional development committee
RDP	Regional development plan
REGIDESO	Régie de production et Distribution d'Eau et d'Électricité

RF	Resettlement framework
Rfd	Reference dose
RGS	Sandy dolomite and feldspathic sandstone
Rh	Rhodium
RIAP	Resettlement interim action plan
RN	Route national
RNI	Reserve naturelle integrale (Nature Integral Reserve)
ROM	Run of mine
RS	Reserve speciale (Special Reserve)
RSA	Regional study area
RSB	Roberts, Synder Baumgartnew. Refer to the RSB model in PLUMES software for dilution modeling
RSC	Roche siliceuse cellulaire (coarse-grained siliceous shale)
RSF	Laminated dolomitic shale
Ru	Ruthenium
RWD	Return water dam
S	South
S	Sulfur
S.A.R.L	Société à responsabilité limitée
s.u.	Standard unit
SADWAF	South African Department of Water Affairs and Forestry
SAGE	Service d'Appui à la Gestion de l'environnement (Support Service for Environmental Management)
SAP	Social action plan
SASS5	South Africa Scoring System Version 5
Sb	Antimony
SC	Soil concentration
SCADA	Supervisory control and data acquisition
SCUBA	Self-contained underwater breathing apparatus
SD	Shale dolomitique (Dolomite and dolomitic shale)
SDP	Social development plan
Se	Selenium
SE	Socio-economic (as in SE survey)

SEASSCAM	Organization of Informal Miners, Kolwezi
SEBR	Socio-economic baseline report
SF	Slope factor
SHEQ	Safety, health and environment quality
Si	Silicon
SiO_2	Silicon dioxide
SLO	Social license to operate
SME	Small and medium enterprise
SMP	Social management plan
SMTF	Société minière de Tenke Fungurume
Sn	Tin
SNCC	Societé Nationale des Chemins de fer du Congo
SO_2	Sulfur dioxide
SO_3	Sulfite
SO_4	Sulfate
SOP	Standard operating procedure
SPCC	Spill prevention, control and counter measure
SPL	Sound pressure level
SPLP	Synthetic precipitation leaching procedure
SPSS	Statistical Package for the Social Sciences
SRDT	Solar Radiation/Delta-T method from the United States Environmental Protection Agency (US EPA)
SRK	Steffen, Robertson and Kirsten Ltd. (UK)
SRR	Spill and release response
STD	Sexually transmitted diseases
STI	Sexually transmitted infections
SVOC	Semivolatile organic compound
SWD	Small woody debris
SWQ	Surface water quality
SX/EW	Solving extraction/electrowinning
t	Tonnes
t/a	Tonnes per annum (same as tonnes per year)
t/d	Tonnes per day

t/h	Tonnes per hour
t/ha	Tonnes per hectare
t/yr	Tonnes per year
Ta	Tantalum
TA-1	Tailings area 1
TBC	To be confirmed
TCU	True color unit
TDS	Total dissolved solids
TEL	Threshold effect level
TFHL	TF Holding Ltd.
TFM	Tenke Fungurume Mining
TFSDP	Tenke Fungurume Social Development Program
Th	Thorium
TIC	Total inorganic carbon
TKN	Total Kjeldahl nitrogen
TLV - TWA	Threshold Limit Values - Time-Weighted Average
TMC	Tenke Mining Corporation (Canada)
TN	Tailings neutralization
ton	Metric ton (1,000 kilograms)
ToR	Terms of reference
tpd	Tonnes per day
TPH	Total petroleum hydrocarbons
tpy	Tonnes per year
Trabeco	Tranverses en Béton du Congo: A concrete railway sleeper factory formerly in Fungurume
TRV	Toxicity reference value
TSF	Tailings storage facility
TSP	Total suspended particulate
TSS	Total suspended solids
TT	Treatment technology
TU	Toxicity Unit
TWA-TLV	Time-Weighted Average - Threshold Limit Values
TWM	Toxic waste management

UBC	United States Uniform Building Code
UET	Upper effect threshold
UHF	Ultra high frequency
UK	United Kingdom
UMCOR	United Methodist Committee of Relief
UMHK	Union Miniére de Haut Katanga
UN	United nations
UN OCHA	United Nations Office for Coordination of Humanitarian Affairs
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
US EPA	United States Environmental Protection Agency
US FDA	United States Food and Drug Administration
USAID	United States Agency for International Development
USD	United States dollars
USDA	United States Department of Agriculture
USGS	United States Geological Services
UTM	Universal transverse mercator
V	Vanadium
VES	Visual encounter surveys
VOC	Volatile organic compounds
VOS	Voluntary observing ships recording
W	Tungsten
Watt/m^2	Watt per meter squared
WBG	World Bank Group
WCMC	World Conservation Monitoring Center
WCPA	World Commission on Protected Areas
WCS	Wildlife Conservation Society
WET	Whole effluent toxicity

WGS	Working groups
WHO	World Health Organization
WMO	World Meteorological Organization
WQ	Water quality
WRC	Water Research Commission, Republic of South Africa
wt	Weight
wt %	Weight percent
WW	Wet weight
WWF	World Wildlife Fund for Nature, or World Wildlife Fund in the United States and Canada
XRD	X-Ray diffraction
XRF	X-Ray fluorescence
yr	year
Zn	Zinc
Zr	Zirconium

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APPENDIX C2.8-I

AIR QUALITY MODELING METHODOLOGY

Methodology

Dispersion models compute ambient concentrations as a function of source configurations, emission strengths and meteorological characteristics, thus providing a useful tool to ascertain the spatial and temporal patterns in the ground-level concentrations arising from the emissions of various sources. Increasing reliance has been placed on concentration estimates from models as the primary basis for environmental and health impact assessments, risk assessments and emission control requirements. It is therefore important to carefully select a dispersion model for the purpose.

For the purpose of the current study, it was decided to use the well-known United States Environmental Protection Agency (US EPA) Industrial Source Complex Short-term model (ISCST3). The ISCST3 model is included in a suite of models used by the US EPA for regulatory purposes. ISCST3 (US EPA, 1995a and 1995b) is a steady-state Gaussian Plume model, which is applicable to multiple point, area and volume sources. Gently rolling topography may be included to determine the depth of plume penetration by the underlying surface. A disadvantage of the model is that spatial varying wind fields, due to topography or other factors cannot be included. A further limitation of the model arises from the model's treatment of low wind speeds. Wind speeds below one meter per second produce unrealistically high concentrations when using the Gaussian plume model and therefore all wind speeds below one meter per second are simulated using one meter per second.

Concentration for various averaging periods may be calculated. It has generally been found that the accuracy of off-the-shelf dispersion models improve with increased averaging periods. The accurate prediction of instantaneous peaks are the most difficult and are normally performed with more complicated dispersion models specifically fine-tuned and validated for the location. The duration of these short-term, peak concentrations are often only for a few minutes and on-site meteorological data are then essential for accurate predictions.

The Industrial Source Complex model is perhaps the subject of most evaluation studies in the United States. Reported model accuracies vary from application to application. Typically, complex topography with a high incidence of calm wind conditions, produce predictions within a factor of 2 to 10 of the observed concentrations. When applied in flat or gently rolling terrain, the US EPA (US EPA, 1986) considers the range of uncertainty to be -50 percent to 200 percent. The accuracy improves with fairly strong wind speeds and during neutral atmospheric conditions.

There will always be some error in any geophysical model, but it is desirable to structure the model in such a way to minimize the total error. A model represents the most likely outcome of an ensemble of experimental results. The total uncertainty can be thought of as the sum of three components: the uncertainty due to errors in the model physics; the uncertainty due to data errors; and the uncertainty due to stochastic processes (turbulence) in the atmosphere.

The stochastic uncertainty includes all errors or uncertainties in data such as source variability, observed concentrations and meteorological data. Even if the field instrument accuracy is excellent, there can still be large uncertainties due to unrepresentative placement of the instrument (or taking of a sample for analysis). Model evaluation studies suggest that the data input error term is often a major contributor to total uncertainty. Even in the best tracer studies, the source emissions are known only with an accuracy of ±5 percent, which translates directly into a minimum error of that magnitude in the model predictions. It is also well known that wind direction errors are the major cause of poor agreement, especially for relatively short-term predictions (minutes to hourly) and long downwind distances. All of the above factors contribute to the inaccuracies not even associated with the mathematical models themselves.

Input data types required for the ISCST3 model include: source data, meteorological data, terrain data and information on the nature of the receptor grid.

Meteorological Requirements

The ISCST3 requires hourly average meteorological data as input, including wind speed, wind direction, a measure of atmospheric turbulence, ambient air temperature and mixing height. Hourly average data was obtained from the Tenke Fungurume mining (TFM) camp for the period 1998 to 1999. The mixing height for each hour of the day was estimated for the simulated ambient temperature and solar radiation data. Daytime mixing heights were calculated with the prognostic equations of Batchvarova and Gryning (1990), while nighttime boundary layer heights were calculated from various diagnostic approaches for stable and neutral conditions.

Receptor Grid

The dispersion of pollutants emanating from the site was modeled for an area covering approximately 31.5 kilometers (East-West) by approximately 19.9 kilometers (North-South). The area was divided into a grid matrix with a resolution of approximately 315 meters (East-West) by approximately 199 meters (North-South). The ISCST3 simulates ground-level concentrations for each of the receptor grid points.

Terrain Data

Terrain data was included into the dispersion model for an area covering approximately 31.5 kilometers (East-West) by approximately 19.9 kilometers (North-South).

Source Data Requirements

Process emissions include routine releases. Since fugitive dust emissions depend on the action of the wind, it was necessary to develop hourly emission rates for each of the fugitive dust sources.

Building Downwash Considerations

Building heights were taken into account in the modeling of current routine emissions so as to account for *building down-wash effects* in the dispersion simulations. The flow characteristics of air moving over the buildings may induce a downwash on the leeward side, drawing the plume to the ground near the source. (Stack heights of greater than twice the height of adjacent buildings are considered not to give rise to the potential for building down-wash effects.) Building down-wash algorithms have been developed for air quality dispersion models such as the ISCST3. These algorithms require additional input to be prepared and included in the model runs. The Building Profile Input Program (BPIP) was applied in the determination of whether or not each of the stack's plumes were subject to structure wake effects, and for the preparation of ISCST3 model input (EPA 1993).

Table 1 Buildings Included in the Dispersion Model for Building Downwash Effects

Building	Building Height (m)	Building Area (m^2)
first aid and fire	3.5	198
main security and gatehouse	3.5	228
change room and locker room	3.5	476
workshop / warehouse	6.9	2,200
crusher control room / ablutions	2.7	100
reagent storage (4)	6.9	1,300
co hydroxide storage	6.9	700
sentry box	3.0	9
heavy vehicle workshop	19	2,576
main control room	3.5	440
light vehicle workshop	6	470
laboratory	3.5	36
crib rooms	3.5	139
sulfur storage	6.9	1,300
airstrip control tower	8.0	29
airstrip hangar	7.0	400

APPENDIX C2.8-II
FUGITIVE DUST EMISSION FACTORS

Materials Handling Releases

The emission factor used for material handling[1] is given as:

$$E_{TSP} = 0.0016 \frac{(U/2.2)^{1.3}}{(M/2)^{1.4}}$$

Where:

- E_{TSP} = Total Suspended Particulate (TSP) emission factor (kilograms dust/tonne transferred).
- U = mean wind speed (meters/second).
- M = material moisture content (percent).
- k = particle size multiplier (dimensionless).

The particle size multiplier varies with aerodynamic particle sizes and is given as a fraction of TSP. For PM30 the fraction is 74 percent, with 35 percent of TSP given to be equal to PM_{10} (US EPA 1998a). Hourly emission factors, varying according to the prevailing wind speed, were used as input in the dispersion simulations.

Crushing

Crushing plants represent significant dust-generating sources if uncontrolled. Dust fallout near crushers also has the potential to become re-entrained of dust emitted by vehicles or by the wind at a later date. The large percentage of fines in this dustfall material enhances the potential for it to become airborne. Fugitive dust emissions due to the limestone crushing operations were quantified using United States Environmental Protection Agency (US EPA) single-valued emission factors[2] for such operations (Table 1).

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1 US EPA 2006. AP 42: Miscellaneous Sources – Aggregate Handling and Storage Piles. Chapter 13.2.4. November. Website: http://www.epa.gov/ttn/chief/pa42/ch13/index.html

2 US EPA 1998. AP 42: Mineral Products industry. Chapter 11.9. October. Website: http://www.epa.gov/ttn/chief/pa42/ch11/index.html

Table 1 United States Environmental Protection Agency Emission Factors for Crushing (US EPA 2001)

Activity	US EPA AP42 Single-Valued Emission Factors (kilograms/tonne)	
	TSP	PM_{10}
primary crushing	0.01	0.004
secondary crushing	0.03	0.012

Blasting and Drilling Operations

Blasting and drilling operations represent intermittent sources of fugitive dust emissions. Single-valued emission factors, published by the US EPA[3] for the quantification of fugitive dust emissions due to drilling operations involving overburden, is given as follows:

E_{TSP} = 0.59 kilograms of dust / hole drilled in overburden

Based on similar processes it was estimated that a total of 7,500 tonnes per year of ANFO (ammonium nitrate/fuel oil) would be used during the proposed operations. The following emission factor for the estimation of fugitive dust emissions, published by the US EPA, was applied:

$$E_{TSP} = 0.00022A^{1.5} \quad \textbf{kilograms/blast}$$

$$E_{PM10} = 0.52 \times 0.00022A^{1.5} \quad \textbf{kilograms/blast}$$

Where:

- E_{TSP} = Total suspended particulate emissions in kilograms/blast.
- E_{PM10} = Inhalable particulates emissions in kilograms/blast.
- A = Horizontal area (square meters), with blast depth of less than or equal to 21 meters.

The US EPA published emission factors for the estimation of carbon monoxide (CO), nitrous oxide (NO_x) and sulfur dioxide (SO_2) emissions from ANFO explosive detonations as 34 kilograms carbon monoxide per tonne, eight

[3] US EPA 1998. AP 42: Mineral Products Industry. Chapter 11.9. October. Website: http://www.epa.gov/ttn/chief/pa42/ch11/index.html

kilograms nitric and nitrous oxides per tonne and one kilogram sulfur dioxide per tonne of ANFO. These emission factors were applied in the current study.

Vehicle Entrained Emissions from Unpaved Roads

Vehicle-entrained dust emissions from unpaved roads represents a potentially important source of fugitive dust. Such sources have been found to account for the greatest portion of fugitive dust emissions from many local waste disposal operations. The force of the wheels of vehicles traveling on unpaved roadways causes the pulverization of surface material. Particles are lifted and dropped from the rotating wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed. The quantity of dust emissions from unpaved roads varies linearly with the volume of traffic.

The unpaved road size-specific emission factor equation of the US EPA[4], used in the quantification of emissions, is given as follows:

$$E = k(\frac{s}{12})^a (\frac{W}{3})^b$$

Where:

- ***E*** = emissions in pounds of particulates per vehicle mile traveled (lb/VMT) – 1 lb/VMT = 281.9 grams/VKT (vehicle kilometers traveled).
- ***k*** = particle size multiplier (dimensionless.)
- ***s*** = silt content of road surface material (percent).
- ***W*** = mean vehicle weight (tonnes).

The particle size multiplier in the equation (k) varies with aerodynamic particle size range and is given as 1.5 for PM_{10} and 4.9 for total suspended particulates (TSP). *a* and *b* are given as 0.9 and 0.45 respectively for PM_{10} and as 0.7 and 0.45 respectively for TSP.

[4] US EPA 2006. AP 42: Miscellaneous Sources – Unpaved roads. Chapter 13.2.2. November. Website: http://www.epa.gov/ttn/chief/pa42/ch13/index.html

The silt content of 8.3 percent was assumed. Site-specific vehicle weights and material throughput were used in the calculation of emissions from this source.

Wind Erosion of Stockpiles

Significant emissions arise due to the mechanical disturbance of granular material from open areas. Parameters which have the potential to impact on the rate of emission of fugitive dust include the extent of surface compaction, moisture content, ground cover, particle size distribution, wind speed and precipitation. Any factor that binds the erodible material, or otherwise reduces the availability of erodible material on the surface, decreases the erosion potential of the fugitive source. High moisture contents, whether due to precipitation or deliberate wetting, promote the aggregation and cementation of fines to the surfaces of larger particles, thus decreasing the potential for dust emissions. Surface compaction and ground cover similarly reduces the potential for dust generation. The particle size distribution of the material on the site is important since it determines the rate of entrainment of material from the surface, the nature of dispersion of the dust plume, and the rate of deposition, which may be anticipated (Burger 1994; Burger et al. 1995).

An hourly emissions file was created for the open exposed area at the plant. An emission rate for every hour of the simulation period was calculated using the ADDAS model. This model is based on the dust emission model proposed by Marticorena and Bergametti (1995). The model attempts to account for the variability in source erodibility through the parameterization of the erosion threshold (based on the particle size distribution of the source) and the roughness length of the surface.

In the quantification of wind erosion emissions, the model incorporates the calculation of two important parameters, viz. the threshold friction velocity of each particle size, and the vertically integrated horizontal dust flux, in the quantification of the vertical dust flux (i.e., the emission rate). The equations used are as follows:

$$E_{(i)} = G(i)10^{(0.134(\%clay)-6)}$$

for

$$G(i) = 0.261\left[\frac{P_a}{g}\right]u^{*3}(1+R)(1-R^2)$$

and $$R = \frac{u_*^{\,t}}{u^*}$$

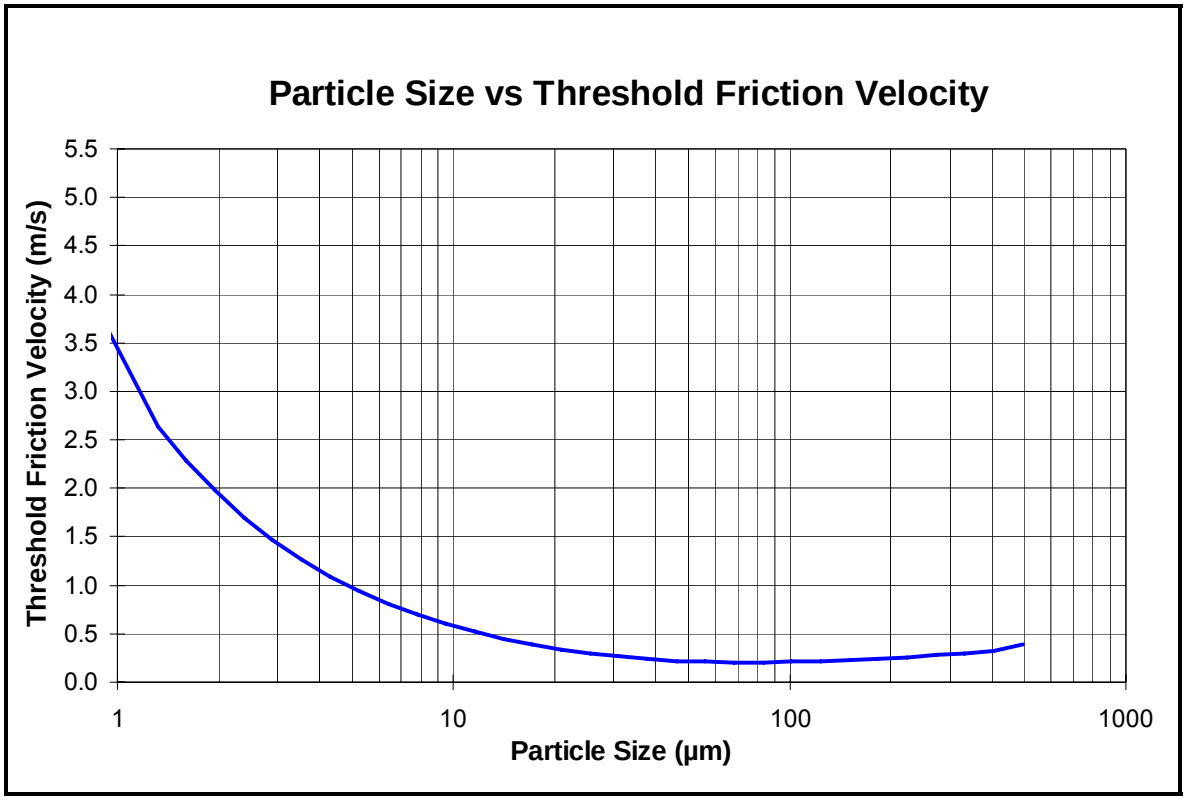
Where:

- $E(i)$ = emission rate (gram/square meter/second) for particle size class i.
- P_a = air density (gram/cubic centimeter).
- $G(i)$ = gravitational acceleration (centimeter/second).
- u_*^t = threshold friction velocity (meter/second) for particle size i.
- u^* = friction velocity (meter/second).

Dust mobilization occurs only for wind velocities higher than a threshold value, and is not linearly dependent on the wind friction and velocity. The threshold friction velocity, defined as the minimum friction velocity required to initiate particle motion, is dependent on the size of the erodible particles and the effect of the wind shear stress on the surface. The threshold friction velocity decreases with a decrease in the particle diameter, for particles with diameters greater than 60 microns. Particles with a diameter less than 60 microns result in increasingly high threshold friction velocities, due to the increasingly strong cohesion forces linking such particles to each other (Marticorena and Bergametti, 1995). The relationship between particle sizes ranging between one micron and 500 microns and threshold friction velocities (0.24 meters per second to 3.5 meters per second), estimated based on the equations proposed by Marticorena and Bergametti (1995), is illustrated in Figure 1.

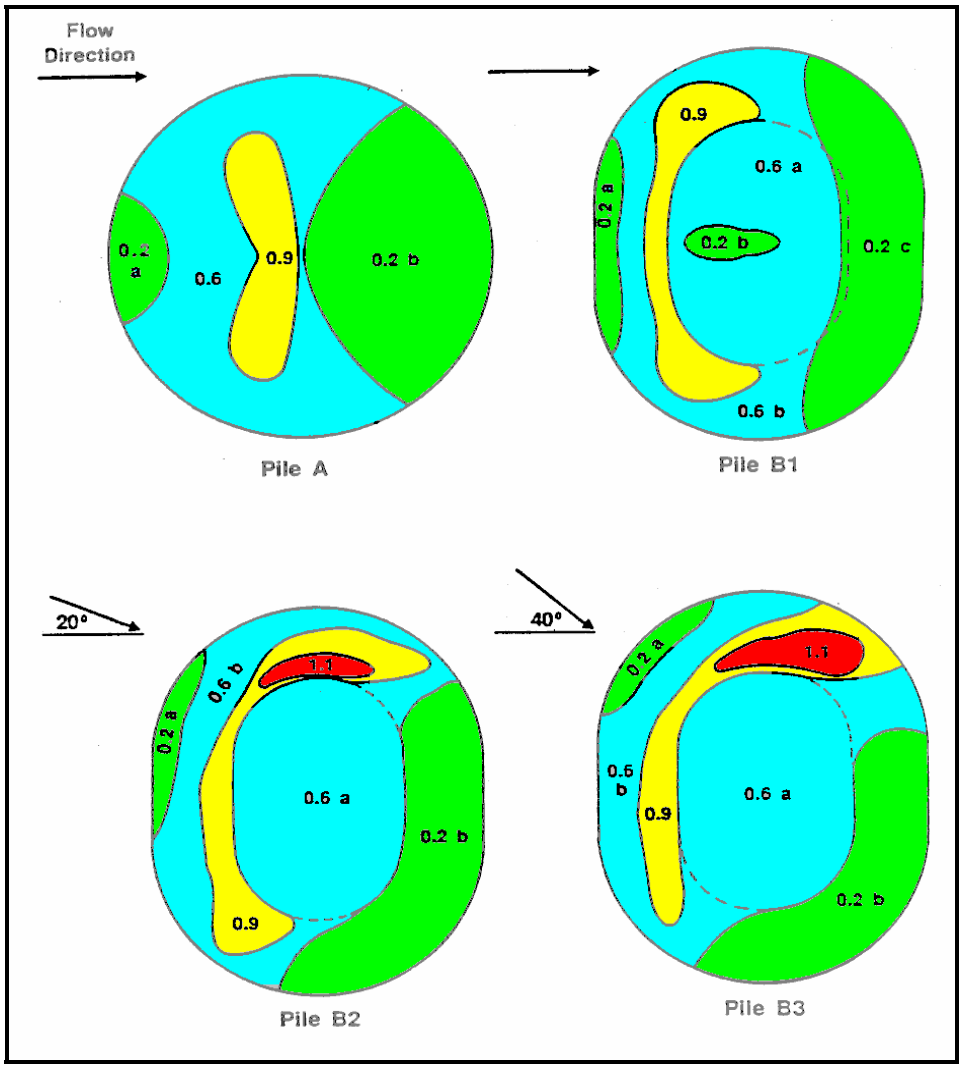
The wind speed variation over the storage piles is based on the work of Cowherd et al. (1988). With the aid of physical modeling, the US EPA has shown that the frontal face of an elevated pile (i.e., windward side) is exposed to wind speeds of the same order as the approach wind speed at the top of the pile. The ratios of surface wind speed (us) to approach wind speed (ur), derived from wind tunnel studies for two representative pile shapes, are indicated in Figure 2 (viz. a conical pile, and an oval pile with a flat top and 37 degree side slope). The contours of normalized surface wind speeds are indicated for the oval, flat top pile for various pile orientations to the prevailing direction of airflow (the higher the ratio, the greater the wind exposure potential). These flow patterns are only applicable with piles that have a height to base ratio of more than 0.25.

Figure 1 Relationship Between Particle Sizes and Threshold Friction Velocities Using the Calculation Method Proposed by Marticorena and Bergametti (1995)



m/s = meters per second.
µm = microns.

Figure 2 **Contours of Normalized Surface Wind Speeds (i.e., Surface Wind Speed / Approach Wind Speed) (After US EPA 1996).**



The roughness length used for the calculation of wind erosion from the storage piles was taken as 0.003 meters.

APPENDIX C2.8-III
SOURCE AND EMISSIONS DATA USED FOR DISPERSION MODELING PURPOSES

Source and Emission Data used for Dispersion Modeling Purposes

The following information/assumptions is a summary of the information used for the dispersion modeling purposes (Table 1).

Table 1 Stack Parameters Used for Dispersion Modeling Purposes

Stack	X	Y	Altitude (m)	Stack Height (m)	Stack Diameter (m)	Exit Gas Temperature (°C)	Volumetric Flow Normal (m^3/hr)	SO_2 Weight (%)	CO_2 Weight (%)
leach	221347.7	326672.1	1,399.6	10	0.8	34	7,754	0.09	68.9
iron removal	221475.1	326705.2	1,401.6	15	0.6	49	2,718	0	62.8
iron removal	221475.1	326705.2	1,401.6	15	0.45	47.3	6,430	0.09	4.5
iron removal	221475.1	326705.2	1,401.6	15	0.45	47.3	6,430	0.09	4.5
iron removal	221475.1	326705.2	1,401.6	15	0.45	47.3	6,430	0.09	4.5
CO dissolution scrubber	221653.8	326793.3	1,401.8	15	0.35	37.9	521	0.22	0.0
copper precipitation	221549.8	326741.2	1,402.0	15	0.35	45.4	461	0.38	0.0
copper precipitation	221549.8	326741.2	1,402.0	15	0.35	45.4	461	0.38	0.0
copper precipitation	221549.8	326741.2	1,402.0	15	0.2	45.4	461	0.38	0.0

m = meters.
°C = degrees celcius.
m^3/hr = cubic meters per hour.
% = percent.

Stacks

The leach discharge thickener and leach feed thickener were not included as the carbon monoxide and sulfur dioxide emissions are zero.

The Acid Plant

The sulfuric acid (H_2SO_4) production was taken to be 600 tonnes per day for the 115 kilotonnes per year scenario and 1200 tonnes per day for a 200 kilotonnes per year scenario. The sulfur dioxide (SO_2) and sulfite (SO_3) emissions per tonne hydrogen sulfate was taken to be 2.0 kilograms and 0.075 kilograms respectively. For start-up (upset) conditions twice the routine emissions was assumed (Table 2).

Table 2 Stack Parameters for the Acid Plant Used for Dispersion Modeling Purposes

Stack	X	Y	Alt (m)	Stack Heightt (m)	Stack Diameter (m)	Exit Gas Temperature (°C)	Volumetric Flow Normal (m^3/hr)
acid plant	221412	326771	1,400	50	0.9	80	26,678

m = meters.
°C = degrees celcius.
m^3 = cubic meters per hour.

Materials Handling

Although the crushed ore stockpile was given as covered, the assumption was made that this materials handling operation would be open and exposed to emission releases (Tables 3 and 4).

Table 3 Parameters for Material Handling Operations

Source	Activity	Throughput (t/d)	Moisture (%)	Release Height (m)	Length (m)	Width (m)	Height (m)
run of mine pad	truck	7,560	2	3.8	4.5	4.5	3.5
run of mine bin	loader truck	7,560	2	4.2 3.8	3	3	3
crusher discharge conveyor	crusher/apron feeder	7,560	2	2.8	2	2	2
crushed ore bin	mill feed conveyor	7,560	2	6.2	1.2	1.2	1.5
mill feed conveyor	belt feeder	7,560	2	2.8	1.2	1.2	2.5
dolomite pad	truck	249	2	3.8	3	3	3
dolomite crusher feedbin	loader truck	249	2	4.2 3.8	2.5	2.5	2.5
dolomite crusher discharge conveyor	crusher/apron feeder	249	2	0.45	0.3	0.9	0.3
dolomite mill feed bin	screen	249	2	1	3	3	3
dolomite secondary crusher	screen	249	2	0.9	1.1	1.4	0.6
dolomite mill feed conveyor	belt feeder	249	2	1.1	0.9	0.5	0.8

t/d = tonnes per day.
% = percent.
m = meters.

For tipping operations at the mine the following information was used:

Table 4 Parameters for Material Handling Operations for Mining Operations

Source	X	Y	Alt (m)	Through put (t/d)	Moisture (%)	Release Height (m)	Length (m)	Width (m)	Height (m)
ore to truck at mine	22,1168	32,5606	1,400	7,123.28 7,671	8	3.8	4.5	4.5	3.5
waste to truck from mine	22,1274	32,5583	1,400	16,438.3 5,616	8	3.8	4.5	4.5	4.5
waste from truck to SP	22,0137	32,7910	1,500	16,438.3 5,616	8	3.8	4.5	4.5	4.5

m = meters.
t/d = tonnes per day.
% = percent.

Crushing Activities

Use of surface miners negates the use of crushers at the mine site. The emissions from the primary and secondary limetone crusher will be directed to a baghouse. A control efficiency of 80 percent was assumed for the baghouse.

Table 5 Parameters for Crushing Activities

Source	Activity	Crushing and Screening (tonnes/day)	No of Days Per Year	Operation Hours Per Year
dolomite	crushing operations	249.00	365	8,100
	primary crushing and screening	249.00	365	8,100
	crushing operations	249.00	365	8,100
	secondary crushing and screening	249.00	365	8,100

Drilling and Blasting

The following information was used for dispersion modeling purposes:

- 80 drill holes per day for ore.
- 150 drill holes per day for waste.
- Given 7,500 tonnes per year ANFO (ammonium nitrate/fuel oil) explosive used, 230 holes per day, therefore equates to 125.4 kilograms per hole.
- Given two blasts per day, five days per week.

- Assumed blasts will occur at 10:00 hours and 14:00 hours.
- Assumed drilling is continuous for 24 hours a day, five days a week.
- Drill spacing given as 3.75 meters and 4.4 meters for ore and waste respectively.

Stockpiles

The silt content, bulk and particle density were assumed (Table 6).

Table 6 Parameters for Storage Piles

Source	Moisture (%)	Height (m)	Silt (%)	Bulk Density (kg/m³)	Particle Density (g/cm³)
reclaim ore (crushed ore)	2	12	0.2	1,700	3.4
limestone	2	2	0.2	1,240	2.48
waste rock facility	8	120	6	2,200	3.3
run of mine pad	2	20	0.2	1,700	3.4
topsoil	8	2.5	15	1,522	3
tailings storage facility	15	65	0.7	1,800	3.6
waste rock at Goma	8	90	6	2,200	3.3

Particle Sizes

The particle size fractions are given in Table 6.

Vehicle Activity

Information concerning the road activity is given below (Tables 7 and 8). Payload for most of the truck activity was given and empty truck weights for these sources were assumed. Average weight of the trucks on specific roads was calculated weighting these values to the trips taken. The silt content on the road was assumed to be 8.3 percent based on default values given for the United States Environmental Protection Agency (US EPA).

Table 7 Particle Size Fractions

Screen (µm)	Waste Rock	Ore	Reclaim Ore	Tailings	Limestone	Topsoil	Unpaved Roads
2,000	0.47	0.998	0.9848		0.95		
1,000		0.001	0.0076		0.025		
425	0.2						
355						0.034	
350		0.00065	0.00494		0.01625		
300		0.00005	0.00038		0.00125		
250				0.022			
212						0.077	
150		0.00015	0.00114	0.04	0.00375		
125						0.056	
106				0.19			
100		0.00005	0.00038		0.00125		
75	0.11	0.000025	0.00019		0.000625	0.099	
53				0.6			
50		0.000025	0.00019		0.000625		
45				0.08		0.117	
40	0.03						
30		0.00002	0.000152	0.022667	0.0005	0.179	0.4
27	0.03						
15				0.022667		0.076	0.09
13	0.06						
10		0.00002	0.000152	0.007556	0.0005	0.117	0.3
5	0.04	0.000005	0.000038	0.007556	0.000125	0.081	
3						0.107	
2.5							0.21
2	0.06	0.000003	0.0000228	0.004533	0.000075		
1		0.000002	0.0000152	0.003021	0.00005	0.057	

µm = microns.

Table 8 Source Parameters for the Road Activity

Road	Material	t/d	Empty Weight (t)	Payload (t)	Average Weight (t)	Average Trips/Day	Average Return Trips
from quarry	limestone	249	71	34	88	7	15
from mine to waste dump	waste	16,438.36[(a)] 37,805.48[(b)]	71	34	88	482[(a)] 1,112[(b)]	964[(a)] 2,223[(b)]
from mine to crusher	run of mine pad	7,123.29[(a)] 15,016.44[(b)]	71	34	88	222[(a)] 442[(b)]	444[(a)] 883[(b)]
to distributors	copper	274	19	34	53	8	16
	cobalt	22	19	34	53	0.6	1
road from Fungurume towards plant	reagents and fuel	700	19	34	40	21	40
raw material	sulfur	207	19	34	53	6	12
raw material	quicklime	135	19	34	53	4	8
raw material	magnesia	33	21	30	36	2	3
raw material	coagulant/ diluent	1.8	21	30	36	0.1	0.2
raw material	fuel tanker	31	21	30	36	1	2
raw material	other reagents	17	19	34	53	0.5	1

t/d = tonnes per day.

t = tonnes.

[(a)] Incremental scenario.

[(b)] Cumulative scenario.

APPENDIX C2.8-IV
METHODOLOGY USED TO CALCULATE EMISSIONS FROM EVAPORATION PONDS

As well as point source emissions, emissions were also calculated from the raffinate ponds. Volatile organic compounds will be released from the ponds. In order to calculate the emissions from these sources, use was made of the National Pollutant Inventory (NPI) emissions estimate technique manual for organic chemical processing industries.

The evaporation rate of compounds into the atmosphere is given by the following equation:

$$Ei = 1.2 \times 10^{-10} (M(p^0{}_i)/T) u^{0.78} x^{0.89} y$$

Where:

Ei = evaporation rate of substance "i" (g/s)

u = wind speed over the surface of the spill (cm/s)

x = downwind dimension (cm)

y = crosswind dimension (cm)

M = molecular weight

$p^o{}_i$ = vapor pressure of substance "i" at temperature of liquid T (dyne/cm^2 = 0.0001 kPa)

T = temperature (K)

The parameters used for the current study were as follows:

u = 0.5 m/s

x = 45 m

y = 45 m

M = 174 kg/kg mol

$p^o{}_i$ = 0.188407 based on Shellsol D70

T = 313.15 K

APPENDIX C2.8-V
CALCULATION OF SULFURIC ACID MIST EMISSIONS FROM SX/EW TANKHOUSE

The following sections describe the derivation of equations used to calculate annual acid mist emissions.

Driving Mechanisms for Natural Ventilation

The two driving forces that produce natural ventilation in a building are wind pressure (wind effect) and thermal buoyancy (stack effect) caused by a temperature difference.

Flow due to wind effect (Q_w):

Factors affecting ventilation wind forces include average velocity, prevailing direction, seasonal and daily variation in velocity and direction, and local obstructions such as nearby buildings, hills, trees, and shrubbery. The following equation shows the quantity of air forced through ventilation inlet openings by wind:

$$Q_w = (88) C_w A_w V \quad (1)$$

where Q_w = wind effect air flow (ft^3 /min)

C_w = effectiveness of openings (orifice coefficient)

A_w = area of windward inlet openings (ft^2)

V = wind velocity (MPH)

88 = conversion factor (MPH to ft/min)

Flow due to stack effect (Q_s):

The pressure flow relationship for the movement of air through a building is given by the following equation:

$$h_{th} = h(1 - s_h) \tag{2}$$

where h_{th} = thermostatic head (ft of air)

h = height of feet of hot air in an enclosure

s_h = specific gravity of hot air relative to cold air

But, since the specific gravity of the cooler air is equal to unity (since it is made the point of reference), s_h becomes:

$$s_h = \frac{s_c T_o}{T_i} = \frac{T_o}{T_i} \tag{3}$$

where s_c = specific gravity of cool air in an enclosure

T_i = absolute temperature of the hot interior air

T_o = absolute temperature of the cooler air

Combining equations (2) and (3):

$$h_{th} = h(1 - \frac{T_o}{T_i}) = h\frac{(T_i - T_o)}{T_i} = h\frac{\Delta T}{T_i} \tag{4}$$

Since the value of h_{th} is in feet of air, it can be used directly in the following equation to ascertain velocity through an orifice:

$$v = C_s\sqrt{2gh_{th}} \quad (5)$$

where v = orifice velocity (ft/s)

C_s = effectiveness of openings (orifice coefficient)

g = gravitational constant (32.2 ft/s^2)

h_{th} = thermostatic head (ft)

Combining equations (4) and (5):

$$v = C_s\sqrt{(2)(32.2)h\frac{\Delta T}{T_i}} = 8.02C_s\sqrt{h\frac{\Delta T}{T_i}} \quad (6)$$

Orifice flowrates can be calculated by multiplying the orifice velocity by the orifice cross sectional area:

$$Q_s = (8.02)(60)C_sA\sqrt{h\frac{\Delta T}{T_i}} \quad (7)$$

where Q_s = stack effect air flow (ft^3/min)

A = flow area (ft^2)

60 = conversion factor (ft/s to ft/min)

According to the ASHRAE Fundamentals Handbook, the thermal effect flowrate is greatest when the inlet and outlet openings are equal. In the case of unequal

openings, the smaller area should be used in the equation and the flowrate corrected using the correction factor F_c. This correction is determined from Figure 7 located on page 26.11 of the 2005 Fundamentals Handbook.

To calculate h, the following equation can be used:

$$h = \frac{H}{1 + \frac{A_1^2 T_i}{A_2^2 T_o}} \tag{8}$$

where A_1 = area of lower openings (ft^2)

A_2 = area of upper openings (ft^2)

H = distance from lower to upper openings (ft)

Combining equations (7) and (8), and taking into account the correction factor, F_c:

$$Q_s = (481.2) F_c C_s A \sqrt{\frac{\frac{H\Delta T}{T_i}}{1 + \frac{A_1^2 T_i}{A_2^2 T_o}}} \tag{9}$$

Combining wind effect and stack effect flowrates:

Wind effect and stack effect ventilation rates are combined according to the following equation:

$$Q = \sqrt{Q_w^2 + Q_s^2} \tag{10}$$

Substituting equations (1) and (9) into (10) yields the final equation:

$$Q = \sqrt{(7{,}744)C_w^2 A_w^2 V^2 + (231{,}533.44)F_c^2 C_s^2 A^2 \frac{\frac{H\Delta T}{T_i}}{1 + \frac{A_1^2 T_i}{A_2^2 T_o}}} \qquad (11)$$

Calculation of acid mist emission

When the ventilation rate and acid mist concentration are known, the acid mist emissions can be determined from the following equation:

$$E_A = kQZ \qquad (12)$$

where E_A = Acid mist emission rate (ton/yr)

k = Conversion factor

Z = Acid mist concentration (mg/m^3)

Constants Used in Calculating Annual Acid Mist Emissions

The following table summarizes the constants use for the emissions calculation:

Constant	Value	Units
A_1	1647	ft^2
A_2	2625	ft^2
A_w	730	ft^2
C_s	0.55	N/A
C_w	0.55	N/A
F_c	1.18	N/A
h	29.7009	ft
H	38.9	ft
Q_s	335,353	ft^3 /min
Q_w	353,320	ft^3 /min
T_i	523	° R
T_o	515	° R
ΔT	7	° R
V	10	MPH
Z	1	mg/ m^3

Annual Acid Mist Emissions

Using the equations derived and the constants listed, the total annual acid mist emissions is 7.25 tons per year for the copper tankhouse and 3.64 tons per year for the cobalt tankhouse.

APPENDIX C2.10-I

TENKE FUNGURUME PROJECT
GROUNDWATER MODELING
FOR
KWATEBALA OPEN PIT,
TAILINGS STORAGE FACILITYAND WASTE ROCK STOCKPILES

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APPENDIX C2.10-I

TENKE PROJECT
GROUNDWATER MODELING

FOR

KWATEBALA OPEN PIT, TAILINGS STORAGE FACILITY AND WASTE ROCK STOCKPILES

Submitted to:

Phelps Dodge Mining Company
Phoenix, Arizona

March 2007

7908/8628/15/G

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Attachment 2 Groundwater Level Measurements
Attachment 3 Pumping Test Hydrographs
Attachment 4 Groundwater Quality Data

1 INTRODUCTION

1.1 TERMS OF REFERENCE

Golder Associates Ltd and Golder Associates Africa (Pty) Ltd. (Golder) were requested by Phelps Dodge Mining Company (PDMC) to determine the potential impacts from the proposed Kwatebala open pit mine, tailings storage facility, waste rock storage facility and low grade ore stockpiles on the groundwater regime of the area in the vicinity of the proposed Kwatebala project footprint. A groundwater flow model has been constructed and calibrated to provide input to the environmental and social impact assessment (ESIA). This report describes and outlines the methodology adopted in order to achieve the objectives set out in Section 1.2.

1.2 OBJECTIVES

The main objectives of the work are:

- To evaluate existing geological and hydrogeological data to develop a conceptual model of the Kwatebala area.
- To construct a regional groundwater flow model that covers the mine and surrounding area, includes all major mine infrastructure and is supported by the conceptual model. The model would cover the anticipated hydrogeological conditions of the region and thus provide an assessment of the likely range of project impacts on the groundwater system.
- To calibrate the groundwater flow model to steady-state groundwater conditions, based on available data.
- To use the groundwater flow model to simulate groundwater flow scenarios in the Kwatebala area as part of the ESIA to determine:
  - The quantity of groundwater that will enter the pit as mining proceeds below the water table and will be required to be removed as pit dewatering.
  - The impacts of pit dewatering on local and regional groundwater levels and effects on local wells, seeps/springs and surface water baseflow during mining and closure/post-closure.
  - The flowpaths of seepage from the lined tailings storage facility and unlined waste rock stockpiles and ore stockpiles and time to travel to surface water.
  - The impacts of pumping water supply wells for mine water supply.

  - The impacts of post closure pit flooding and groundwater flow paths from the pit to surface water.

- To present the results of the groundwater flow modeling in the ESIA for the Tenke Fungurume Mining (TFM) project.

1.3 DELIVERABLES

The deliverable for this investigation is this technical report on the impacts of the TFM project on the groundwater system with a description of the methodology applied in the investigation, analyses and model results.

1.4 REPORT STRUCTURE

The report is organized into two parts. Part 1 is comprised of the conceptual model, presented in Sections 1 through 5. Part 2 is comprised of the numerical model presented in Sections 6 through 8.

Sections of Part 1 are described as follows:

Section 1 – Introduction - This section includes a summary of the terms of reference, objectives and methodology adopted to accomplish the objectives, a statement on project deliverables and report organization.

Section 2 – Regional Description – Provides a regional description of the study area. It describes the site location, regional drainage, springs, surface runoff, topography, rainfall and evapotranspiration.

Sections 3 and 4 – **Geology and Hydrogeology** - Discusses the geology and hydrogeology of the study area, respectively. The hydrogeology section provides a discussion on the hydrogeological units, aquifers and aquitards, the structural controls, water strike depths, groundwater elevations and flow directions, pumping tests and hydraulic parameters (transmissivity, hydraulic conductivity and storativity).

Section 5 - Conceptual Model – Discusses the conceptual model and key concepts and issues associated with the aquifer system (e.g., groundwater system geometry, system boundaries, hydraulic properties, recharge, discharge and flow directions).

Sections of Part 2 are described as follows:

Section 6 – Approach to Numerical Modeling – Describes the modeling software used, the geometry of the model and boundary conditions, hydrogeological properties and the approach to model calibration.

Section 7 – Model Calibration and Sensitivity Analyses – Describes model calibration in detail and provides the main conclusions from the sensitivity analyses.

Section 8 – Impact Assessment – Provides a description of the application of the calibrated model in order to achieve the objectives of the investigation.

Section 9 – Conclusions – Presents a summary of the key conclusions.

Section 10 – References – Presents references cited.

Four attachments provide information on geological logs and well construction for the exploration boreholes and pumping wells, groundwater levels measured in boreholes, pumping test analyses, and water quality from the pumping tests.

2 REGIONAL DESCRIPTION

The groundwater flow model uses information on the physical properties of the project area. These properties include the topography, surface hydrology, groundwater recharge and hydraulic parameters (hydraulic conductivity, storativity and effective porosity that affect groundwater flow and groundwater travel time.

2.1 LOCATION OF THE STUDY AREA

The TFM concession is located in the Shaba region of the Democratic Republic of the Congo. It is located approximately 180 kilometers to the northwest of the town of Lubumbashi and 53 kilometers to the east-northeast of Kolwezi (Figures 1 and 2).

2.2 TOPOGRAPHY

The surface contours for the study area depicted in Figure 3 were determined from satellite data obtained covering a 90 meter grid configuration. Surface elevations vary between 1,120 and 1,695 meters above mean sea level across the study area. The satellite topography data was used to interpolate elevations for boreholes based on the supplied x- and y-locations of each borehole.

2.3 CLIMATE

2.3.1 Rainfall

Climatic information is presented in Section B2.7 and B2.11. The Solwezi station (located in Zambia) and the Lubumbashi station (Luano airport located in the DRC) are the only two regional climate monitoring stations located close to (i.e., within 200 kilometers distance) the study area. Analysis of the data indicates that:

- The mean annual rainfall of the regional area is about 1,200 millimeters.
- The mean annual rainfall in Tenke is about 1,160 millimeters.
- There are distinct wet and dry seasons. The wet season lasts from the middle of October until the end of March.
- Monthly rainfall between December and March exceeds 200 millimeters each month.
- The dry season is between May to September.

Historical annual rainfall totals for Solwezi are depicted in Figure 4.

Figure 1 Location Map

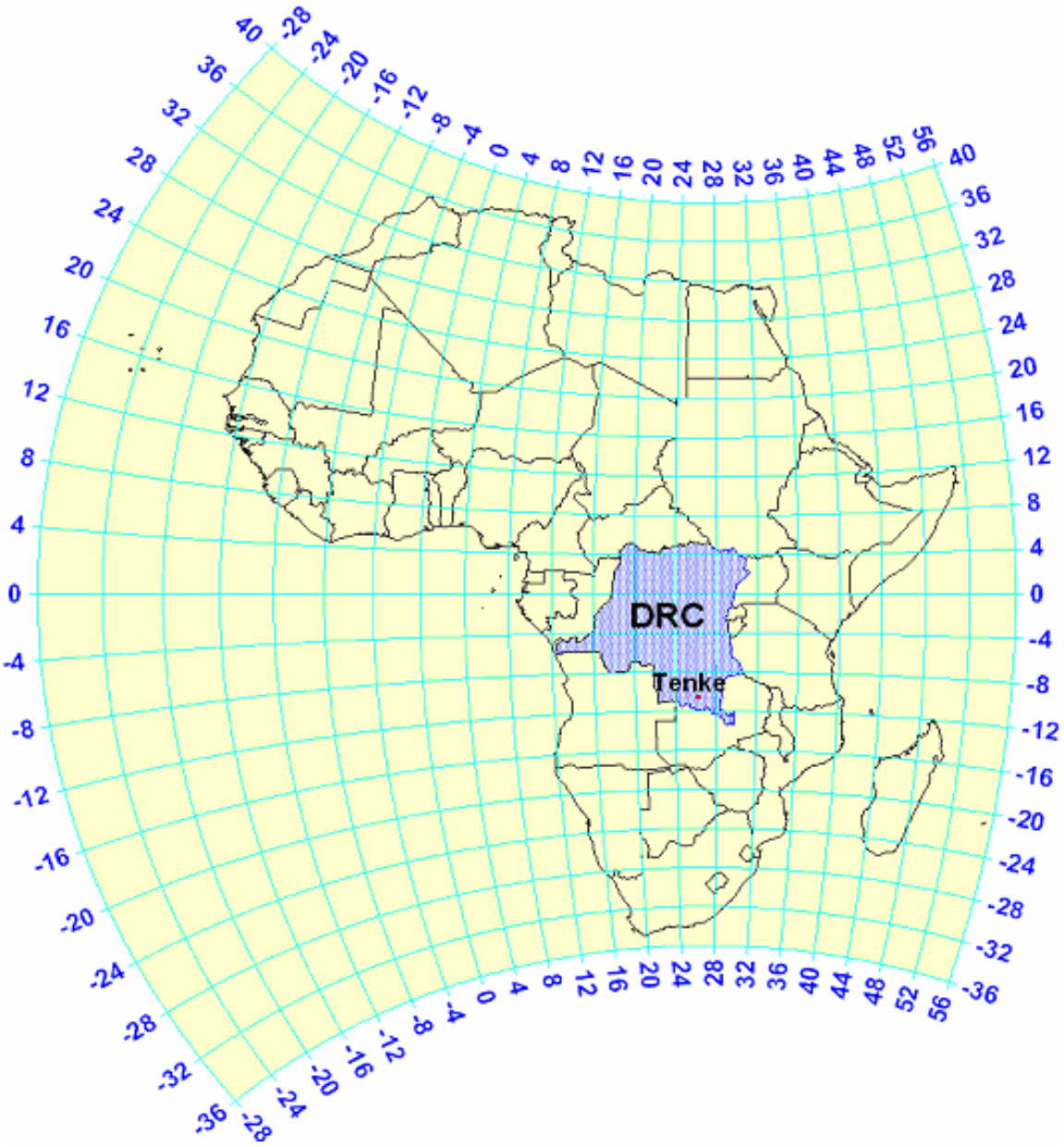
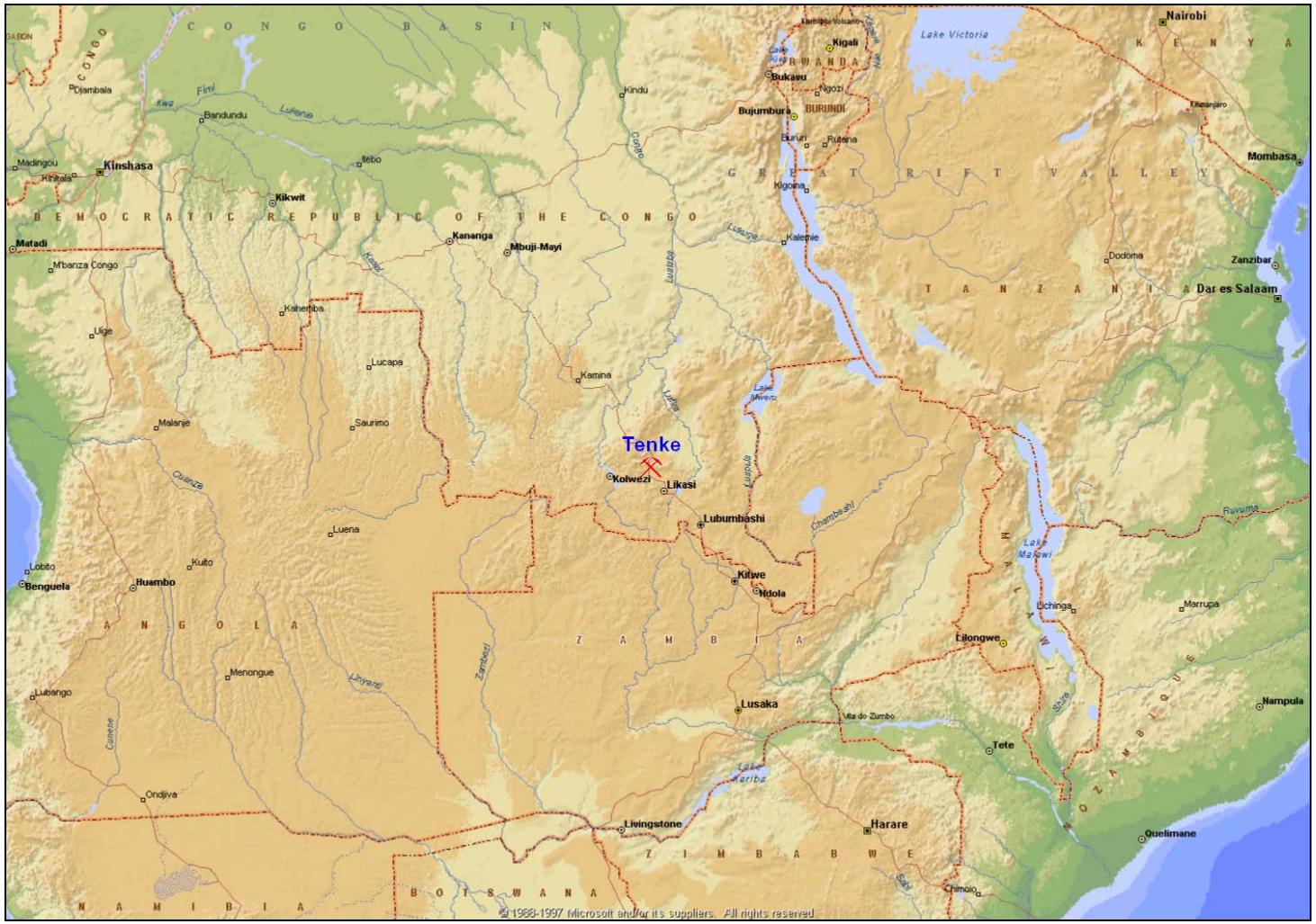


Figure 2 Tenke Mine Location Map



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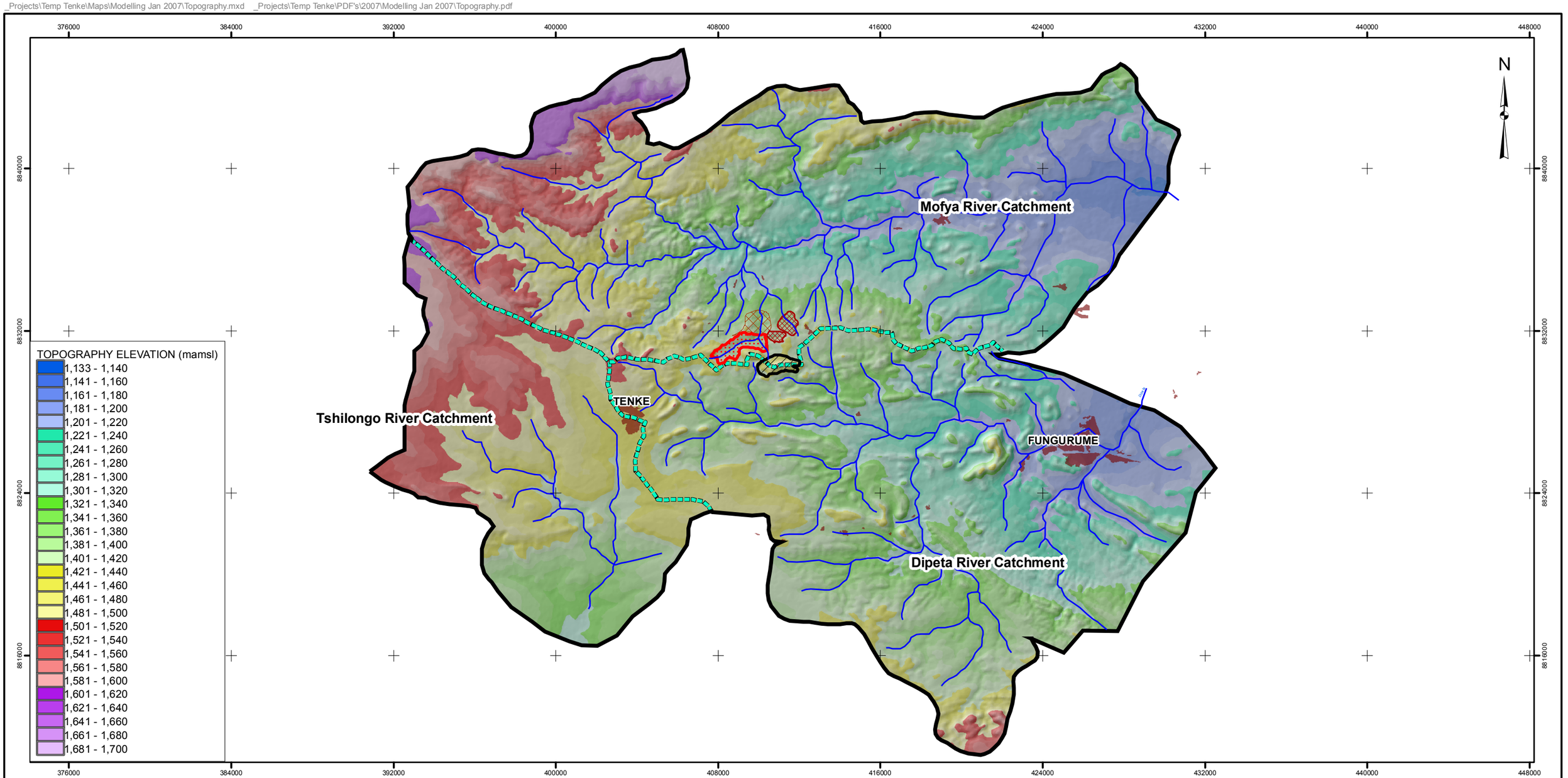

LÉGENDE / LEGEND

- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- CATCHMENT DIVIDE
- RIVER

3 0 3 6 9 12 15

ÉCHELLE 1:190,000KILOMÈTRES
SCALE 1:190,000KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

TOPOGRAPHY AND DRAINAGE OF THE STUDY AREA

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Golder Associates
Johannesburg, South Africa

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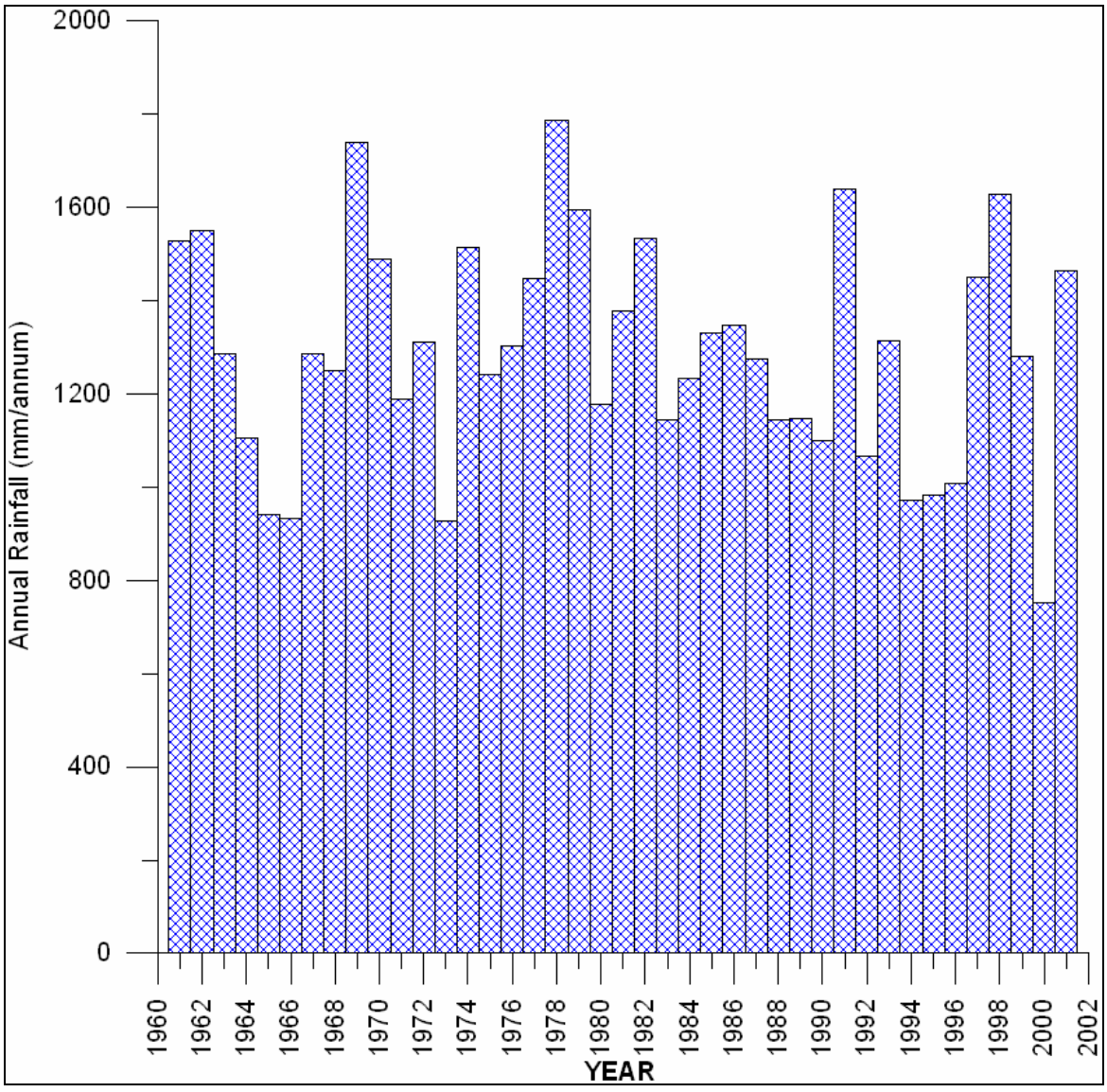
DESSIN / DESIGN	HvR	30 Jan 2007	FIGURE: 3	
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ REVIEW	HvR	30 Jan 2007		

Figure 4 Annual Rainfall Measured at Solwezi



2.3.2 Evapotranspiration

Actual evapotranspiration at Tenke has been estimated as part of the hydrology baseline characterization work (Section B2.11) based on water balance methodology. The estimated annual average actual evapotranspiration is 950 millimeters (Table B.2.11-11).

2.4 HYDROLOGY

2.4.1 Drainage Basins

The TFM concession area lies within two drainage basins, defined by the Dipeta and Mofia Rivers. The proposed Kwatebala infrastructure is located on the surface watershed between the Dipeta (south) and Mofia (north) rivers (Figure 3). The Tshilongo River is located to the west of the Dipeta and Mofia river catchments. There are no mine facilities in the Tshilongo catchment.

The Dipeta River flows generally from west to east and drains the southern regions of the concession area. The Mofia River also flows from west to east but drains the northern regions of the TFM concession area (Figure 3).

The Dipeta River is fed by a number of tributaries in the TFM concession area. The main north flowing tributaries include the Konka, Kakapidi, Kampangu, Kasingangu, Kanwezi, Kamakanda and Kalengile rivers. The Konka River contributes significantly to the flow in the Dipeta River, in the vicinity of Fungurume.

Three main tributaries flow southwards towards the Dipeta River. The tributaries are the Shimpidi, Sokalwela and Kalengimiawa rivers. The Mofia River is fed by a number of tributaries that flow generally northwards through the northern extent of the concession area. The tributaries include the Longe, Kiomba, Kasana, Kanzekenene and Kabomboy rivers.

The Dipeta catchment is about 230 square kilometers, the Mofia catchment is approximately 1,000 square kilometers. Some of the smaller sub-catchments of the Dipeta catchment listed above cover areas of less than 20 square kilometers. The Tshilongo River drains westward and then southwards. A 134 square kilometers sub-catchment of the Tshilongo River is located immediately west of the Dipeta catchment.

In areas where the water table is lower than the stream-bed elevation, surface water is lost to groundwater (losing stream reaches) and the river bed may be dry during certain parts of the year. Examples of dry reaches include the Dipeta River in the narrowing of the valley, Kasanga River and the Kalengimiawa River near the confluence with the Dipeta River (SRK 1998).

2.4.2 Surface Runoff

Surface runoff varies through the catchments and is principally dependent on the soils, surface geology, vegetation coverage and slope. Direct surface runoff is minimal due to the high permeability of the soils and underlying lithology within the Project area which promotes infiltration of precipitation and groundwater recharge rather than direct surface runoff.

2.4.3 Total Runoff

Flows in the various river systems vary significantly due to the size differences between catchments and underlying geology. Table 1 summarizes the simulated flows at the ten surface water monitoring locations (Figure 5) for the wet and dry seasons. The methodology used to simulate surface water flows is described in Section B2.11.5.2. The methodology employed the Agriculture Catchments Research Unit model (ACRU) with streamflow estimated on a daily time step basis.

Surface flow is primarily sustained by groundwater discharge throughout the year due to the lack of surface runoff except during major storm events. The dry season baseflow represents a lower limit for groundwater recharge since some groundwater recharge likely by-passes the gauging stations as groundwater underflow and there could be losses to evapotranspiration in riparian areas along the stream channels.

2.4.4 Groundwater Recharge

Groundwater recharge was estimated based on the catchment water balance presented in Section B2.11 and the ACRU modeling. The modeling indicated that a significant portion of the surface water runoff was provided by groundwater recharge and subsequent discharge as baseflow. Based on this work, a recharge value of 240 millimeters per year has been used as representing average long term conditions for the groundwater model. This value assumes little if any direct surface runoff consistent with the high permeability of the surface soils.

2.4.5 Springs

Springs occur in areas where the water table intersects the stream-bed elevation, possibly in association with lithological contacts or faulting. Examples of such springs are the Shimpidi, Kalengimiawa and Ditoma springs, which are found in the headwaters and along the tributaries of the Dipeta and Mofia rivers. Springs represent discharge of groundwater to surface water. Springs mapped in the vicinity of the Kwatebala operations are shown on Figure 6.

Table 1 Simulated Daily Average Streamflow

Sub-catchment	Catchment Area Above Gauging Station (km^2)	Daily Average Streamflow (L/s)/mm/yr		
		Annual	Wet Season[(a)]	Dry Season[(b)]
upper Dipeta	8.82	63/225	98	29
Sokalwela	7.72	39/147	60	18
Shimpidi	12.01	87/225	125	51
mid Dipeta	106.3	650/190	979	326
Konka	82.02	579/220	826	335
lower Dipeta	233.2	1,972/263	2,799	1,158
upper Mofia	161.2	1,329/256	1,908	759
Kasana	10.33	85/256	122	49
mid Mofia	221.6	1,939/272	2,742	1,149
lower Mofia	389.3	3,481/278	4,893	2,092
annualized average (mm/yr)		236		131

[(a)] October to March

[(b)] April to September

Source: Modified from Table B2.11-15 – Tenke ESIA Hydrology Baseline

2.4.6 Water Balance

The following assumptions were made:

- Annual precipitation = 1,160 to 1,200 millimeters per year.
- Potential evapotranspiration = 1,040 millimeters per year.

There would therefore be a minimum of 120 to 160 millimeters per year of water available for runoff and groundwater recharge. However, evaporation during the dry season is limited because of the lack of rainfall and limited soil moisture and thus does not occur at the potential rate. Therefore, it is more reasonable to assume that runoff and recharge is in the range of 200 to 250 millimeters per year as shown on Table 1 with groundwater discharge accounting for a significant proportion (greater than 80 to 90 percent) of the total streamflow.

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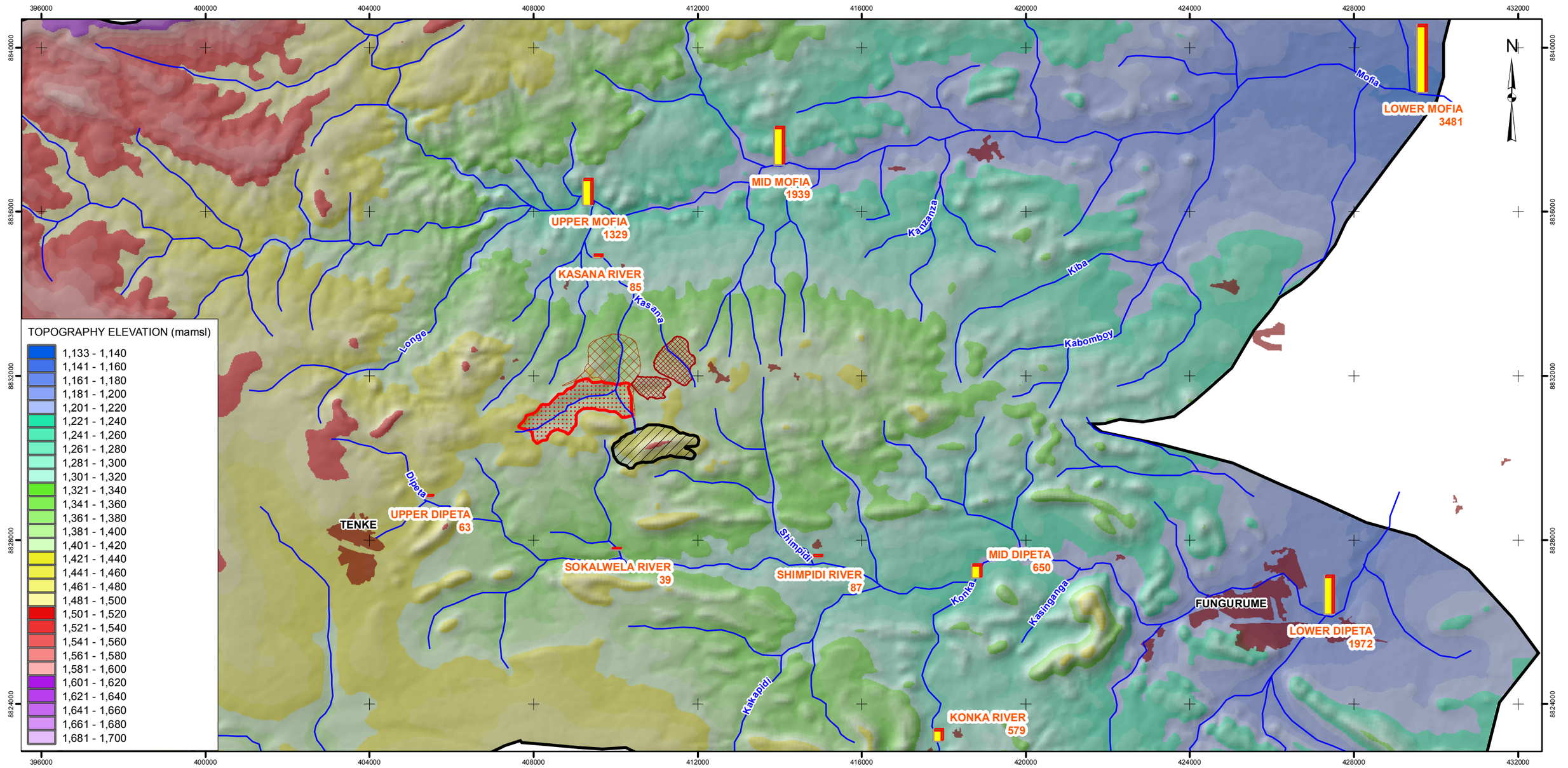

LÉGENDE / LEGEND

- RIVER
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

DAILY AVERAGE FLOW (L/S)

1,700 FLOW

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

1 0 1 2 3 4 5 6 7 8

ÉCHELLE 1:95,000 KILOMÈTRES
SCALE 1:95,000 KILOMETRES

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

LOCATION OF SURFACE MONITORING STATIONS WITH DAILY AVERAGE FLOW

Golder Associates
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GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ REVIEW	HvR	30 Jan 2007	

FIGURE: 5

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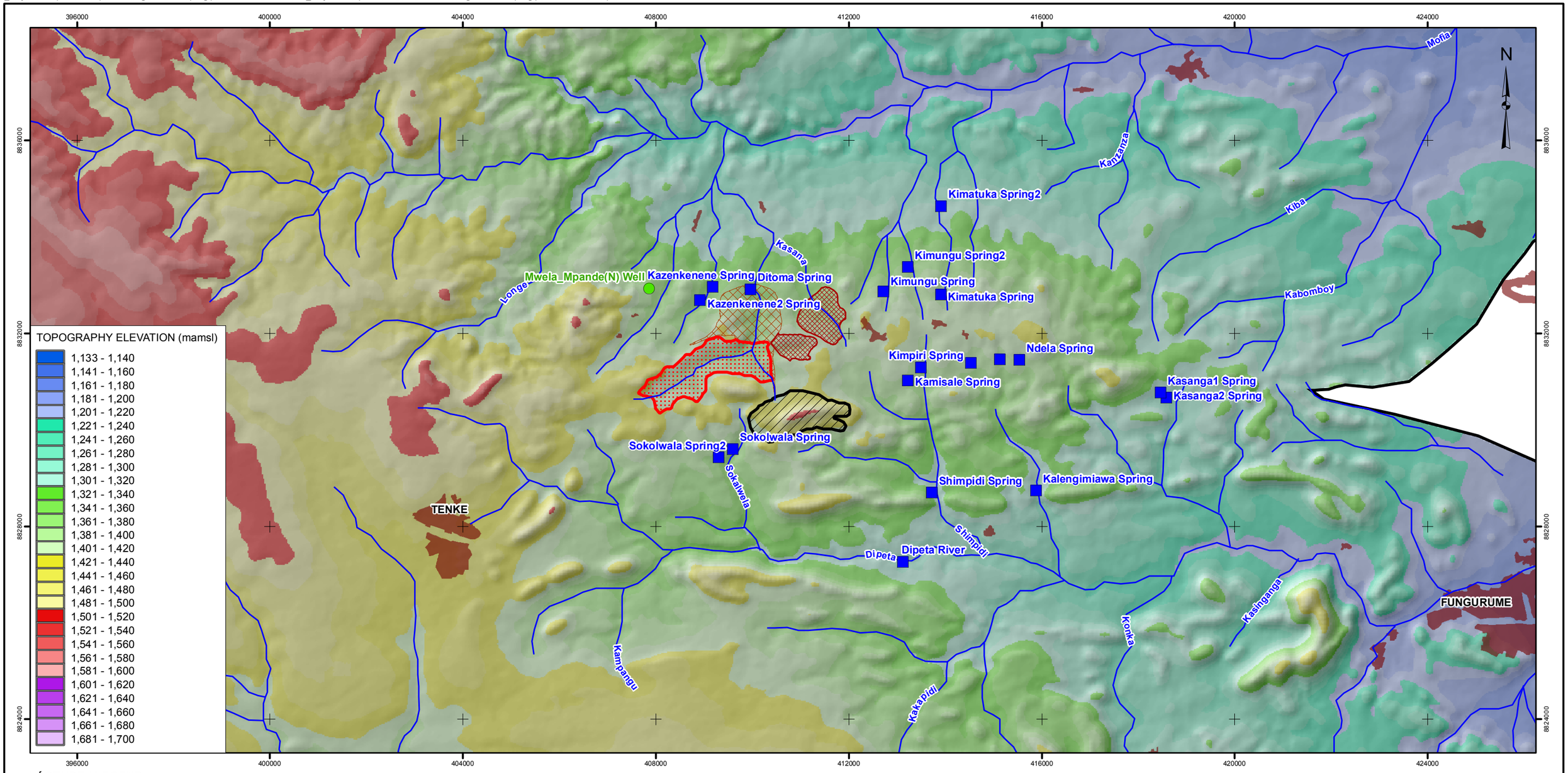

LÉGENDE / LEGEND

- SPRING
- WELL
- RIVER
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

1 0 1 2 3 4 5 6

ÉCHELLE 1:80,000 KILOMÈTRES
SCALE 1:80,000 KILOMETRES

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

SPRING LOCATIONS

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	XX	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ REVIEW	HvR	30 Jan 2007		

FIGURE: 6

In other estimates of groundwater recharge, SRK (1997) estimated infiltration to groundwater based on assumed soil moisture conditions. Their calculation suggests 230 millimeters per year of groundwater recharge. This amounts to approximately 20 percent of the mean annual precipitation (MAP).

Based on the information presented above, the annual average recharge over the project area is assumed to be 240 millimeters per year.

3 GEOLOGY OF THE STUDY AREA

3.1 GENERAL GEOLOGY OF THE TENKE-FUNGURUME AREA

The geological conditions govern the mode and occurrence of groundwater, runoff and infiltration (recharge) and provide the framework for groundwater related environmental impacts from the mining operations.

The geology of the regional study area is structurally complex and although detailed surface maps and cross-sections are available in the vicinity of the proposed mine pit, the remaining areas remain undifferentiated, except on a broad stratigraphic level (Figure 7).

Regionally, the geology underlying the TFM concession comprises a sequence of Kundelungu and Roan Series strata of Pre-Cambrian age. Deposition of these sediments took place in a neo-proterozoic basin straddling the present-day Zambian - Democratic Republic of Congo border. Three major orogenic cycles, namely the Lomamian (ca 950 Ma), the Lusakan (ca 950-850 Ma) and the Lufilian (ca 650-600 Ma) tectono-metamorphic events have affected Katangan rocks (Cailteux et al. 1994).

Jackson et al. (2003) ascribe the presence of spectacular breccias underlying 25,000 square kilometers of the Katangan basin and containing gigaclasts of up to 10 km, to salt tectonics. The former existence of these Roan Supergroup Evaporites are indicated by sabkha facies, crystals and pseudomorphs of gypsum, as well as anhydride, stratigraphic gaps underlain by collapse breccias, chloride inclusions in ores and saline springs. The evaporites were squeezed upwards and outwards during the neo-protozoic Katangan orogeny, followed by 600 million years of dissolution (Jackson et al. 2003).

The stratigraphy of the Roan Series is shown from youngest to oldest in Table 2.

The TFM concession area is part of a major thrust of the Katangan orogeny. The main characteristics of this orogeny are described as follows by SRK (1998) taken from A. Francois (undated).

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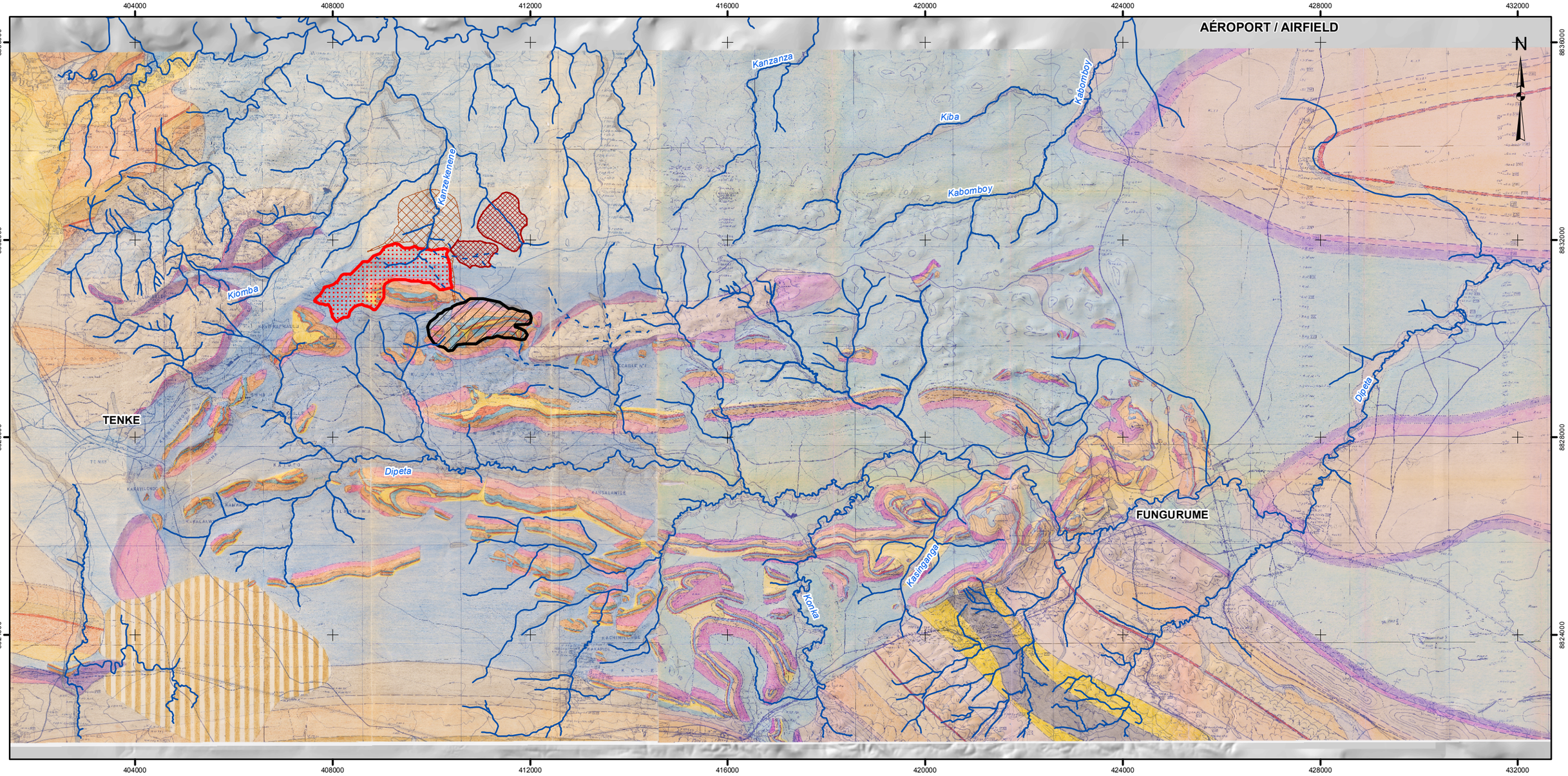

LÉGENDE / LEGEND

- RIVIÈRE / RIVER
- RIVIÈRE INTERMITTENTE / SEASONAL RIVER
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK

Geology

- Mwashya Subgroup — Upper Roan Group — Roan Supergroup
- Dipeta Subgroup (undifferentiated) — Upper Roan Group — Roan Supergroup
- CMN — Mines Series — Middle Roan Group — Roan Supergroup
- SD — Mines Series — Middle Roan Group — Roan Supergroup
- RSC — Mines Series — Middle Roan Group — Roan Supergroup
- RSF — Mines Series — Middle Roan Group — Roan Supergroup
- RAT — Lower Roan Group — Roan Supergroup
- Lower Kundelungu Supergroup

1 0 1 2 3 4 5 6

ÉCHELLE 1:80,000 KILOMÈTRES
SCALE 1:80,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

GEOLOGY OF THE STUDY AREA

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Golder Associates
Johannesburg, South Africa

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DESSIN / DESIGN	HvR	30 Jan 2007	FIGURE: 7
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

The orogeny is subdivided into three tectonic stages which responded differently to the thrust forces:

- The upper stage includes the R4 Group and the Kundelungu Supergroup and is intensely folded.
- The intermediate stage includes the incompetent formations of the Roan Group R1 and part of R3, which embed fragments of more competent formations (R2 and part of R3).
- The lower stage includes the ante-Roan formations which have been moderately affected by the orogeny. This is not visible in the study area.

Table 2 General Stratigraphy of the Roan Supergroup Present in the Tenke-Fungurume Mine Concession Area

Group	Formation	Map Symbol	Geological Description
lower Kundelungu			pelites microsandstones dolomites base conglomerate
upper Roan	Mwashya (R4)	Mw	silicified dolomite
	Mofia	Mo	limestone
	Dipeta (R3)	Di	dolomitic schist, felspathic sandstone and schist. occasional mineralization
	RGS	RGS	sandy dolomite and feldspathic sandstone
middle Roan		CMN	siliceous dolomite and graphitic shale
		SD	dolomite and dolomitic shale, with Cu and Co mineralization at the base (upper ore body)
	(R2)	RSC	coarse grained siliceous dolomite, with some mineralization at the top and base
		RSF	laminated dolomitic shale with Cu and Co mineralization (lower ore body)
		D.Strat	stratified dolomite Cu and Co mineralization
lower Roan		RAT-G	brecciated dolomitic and grey sandy shale
	(R1)	RAT-L	brecciated dolomitic and lilac sandy shale

The incompetent RAT-G and RAT-L is described as a ‘soap’ layer on which the overlying layers have slid (Section B2.10). Under tectonic stresses, the incompetent RAT formations have been squeezed and were injected into anticlines and faults, resulting in the peculiar tectonic structures such as:

- Anticlines with extrusive cores.

- Extrusions of RAT (R1) injected into faults and forming valley bulges in the ridges north and south of the Dipeta Valley.
- Dislocation of competent formations such as the Middle Roan (R2) into fragments described as ecailles (outliers) embedded in RAT (R1).

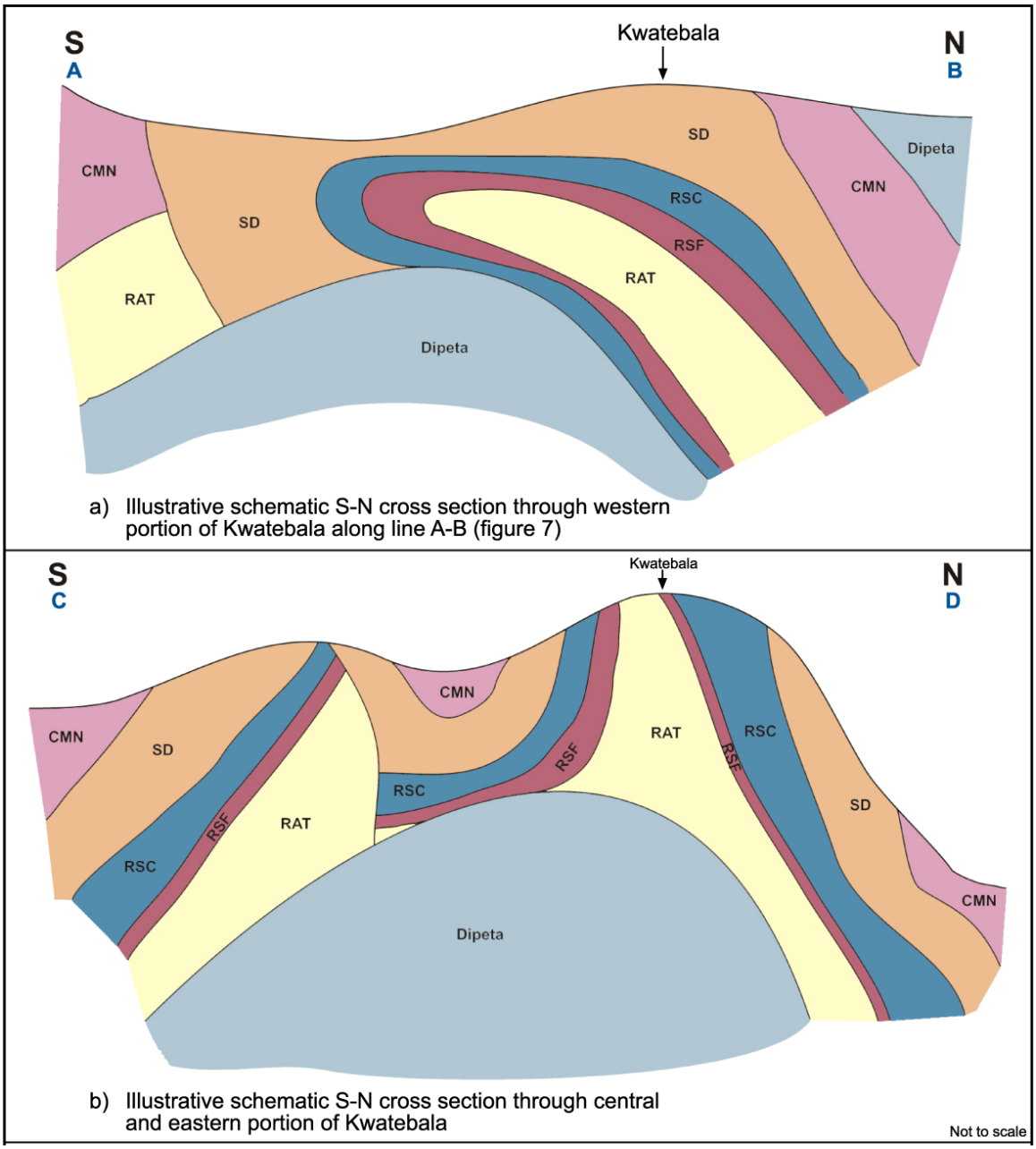
The major structure of the Tenke-Fungurume area is a large east-west syncline in the Roan Supergroup, referred to as the Dipeta syncline. Its east-west axis extends over 16 kilometers along the Dipeta River. The width of the syncline is approximately three kilometers in the Dipeta valley between the RAT formation outcrops. The syncline plunges to the west and has been in-filled with sediments. The syncline is partially closed to the east near Fungurume by the narrowing of the valley and to the west by the narrowing of the valley near Kwatebala and closing near Tenke (SRK 1998). SRK describe the core of the Dipeta syncline as consisting of 400 to 600 meters of Dipeta (R3) and Mwashya (R4) Group formations. The eastern closure of the Dipeta syncline is broken by faulting in a series of small blocks ranging in size from a hundred to a few hundred meters in size, constituting the Fungurume northern deposits (SRK 1998).

To the south of the Dipeta syncline over a distance of two to three kilometers, the Roan Supergroup formations are dislocated in a series of outliers in the shape of small anticlines and synclines, each extending over a few hundred meters and apparently embedded in RAT formations.

To the north of the Dipeta syncline the formations are similarly dislocated in folded and faulted outliers, overturned to the north with a general appearance of monoclines striking east-west and similarly embedded in RAT (SRK 1998). RAT material is also often encountered in fault zones. The Shanika Kundelungu fragment, further north of the Dipeta syncline represents fragments of Mofia and Mwashya (R4) and Kundelungu layers overlying the Roan due to faulting.

The Kwatebala ridge consists of a complexly folded, overfolded and thrusted sequence of thin, mineralised units of the Lower Roan Group, referred to as the Mine Series (RSF, RSC and SDB). Figure 8 illustrates this complexity, which is based on the drilling of cored exploration holes. The complexity of the stratigraphic and tectonic setting of the lithologies away from this ore body is expected to be similar.

Figure 8 **Illustrative Schematic South-North Cross Sections Through Kwatebala**



North of Kwatebala, toward the Mofia River, the current exploration water drilling findings support previous geological descriptions that the greater part of the area is predominantly underlain by rocks of the Upper Roan Group, consisting primarily of carbonates of the Mofia and Dipeta formations, as well as minor exposures of the underlying clastic RGS. The base of the Lower Kundelungu Group is exposed in places.

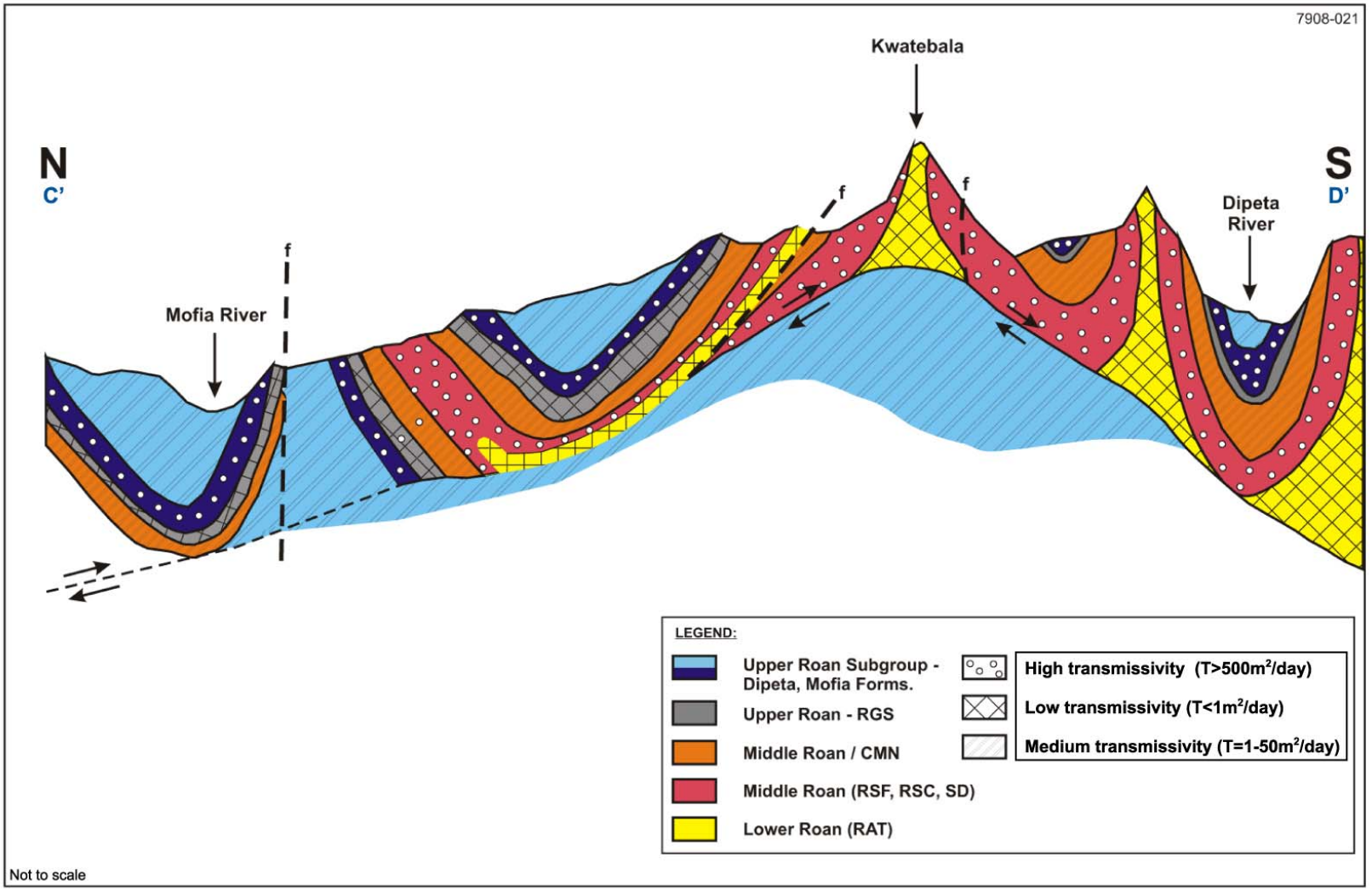
Field geological mapping of the Kabompo Valley in the north-eastern portion of the regional study area suggests that the area to the north of Kwatebala can be included in an east-west trending fold belt along the Mofia River from north of Tenke to as far as east as the Lubudi Road.

The Kabompo Situation Report (1973) suggests that the steep ridges and hills comprise of purple argillite (RGS) forming the crest, flanked in many cases by the Mofia limestone forming steep slopes and cliffs.

Figure 9 is a north-south cross-section of the study area, through Kwatebala Hill. The figure illustrates the complexity of the geology to the north and south of the Kwatebala Hill by extrapolating the known geology from Kwatebala and combining this information from the Kabompo Situation Report (1973), as well as making some inferences from the general topography

.

Figure 9 Illustrative Schematic North-South Cross Section Through Study Area



4 HYDROGEOLOGY OF THE TENKE-FUNGURUME AREA

4.1 HYDROGEOLOGICAL UNITS

Geological interpretation by earlier researchers, results from drilling "water strikes" and pumping tests were used to identify and characterize aquifers occurring in the regional study area. The geological framework is presented in Table 2. The interpreted hydrogeological units are presented in Table 3.

Table 3 Interpreted Hydrogeological Conditions in the Tenke Fungurume Mine Concession Area

Group	Formation	Geological Description	Thickness (m)	Aquifer or Aquitard
upper Roan	Mwashya	silicified dolomite	lower 50-60; upper 0-250	moderate aquifer
	Mofia	limestone and dolomite	50	moderate aquifer
	Dipeta	dolomitic schist, felspathic sandstone and schist	>950	moderate aquifer
	RGS	sandy dolomite and feldspathic sandstone	40-80	moderate aquifer/ aquitard
middle Roan	CMN	siliceous dolomite and graphitic shale	95-165	moderate aquifer/ aquitard
	SD	dolomite and dolomitic shale	30-130	moderate aquifer
	RSC	coarse grained siliceous dolomite	15-35	main aquifer
	RSF	laminated dolomitic shale	5-10	moderate aquifer
lower Roan	D.Strat	stratified dolomite	2 - 4	moderate aquifer
	RAT	brecciated dolomitic and sandy shale	>245 m	aquiclude

4.2 AQUIFERS AND AQUITARDS

The distribution of water strikes in a borehole is evidence of the presence/absence of groundwater and can thus be used as a semi-quantitative assessment of whether the geological units are potential aquifers or aquitards. SRK (1998) reviewed the original exploration boreholes to determine the occurrence of water strikes. This analysis revealed that, of the 40 water strikes recorded, 30 water strikes occurred within the SD, SDB and RSC. This indicated that these lithologies are potential aquifers. Water strikes in the RAT suggested that this unit was somewhat permeable and not necessarily an aquitard.

The RSC dolomite is the major aquifer in the region and is associated within the Dipeta syncline. The CMN, SD and RSF dolomites are also considered to be aquifers, but with a lower permeability than the RSC.

The RAT, which underlies the dolomitic units, is interpreted to be of low permeability and thus classified as an aquitard. This unit may be a localized base of the groundwater flow system with little groundwater flow across this unit. Earlier work (AGC 1973 and Wellfield Services 1975) suggests that the Upper Roan RGS is a low permeability unit and thus potentially an aquitard. Work also suggests that the Dipeta formation above the RGS is moderately transmissive with highly transmissive units associated with the Mofia Limestone.

There is no alluvial aquifer associated with the upper Dipeta River and the river is in direct hydraulic communication with the main dolomitic aquifer within the Dipeta syncline (SRK 1998).

4.3 STRUCTURAL CONTROLS

AGC and Wellfield Services interpreted that faulting and/or thrusting within the Dipeta syncline may have resulted in the truncation of aquifers by low permeability fault/thrust zones or the offsetting of permeable dolomitic zones against relatively less permeable formations such as the RAT and RGS. This would have the effect of limiting the groundwater supply from the aquifers by creating groundwater "compartments" supplied by limited local recharge.

Based on previous investigations, the following generalized aquifer regions (compartments) have been identified:

- The Dipeta Aquifer – associated with the Dipeta syncline. Groundwater flows mostly in the RSC, Dipeta and Mofia dolomites which form the outcrops, appear relatively continuous and strike east-west (SRK 1998).
- The North Aquifer – consists of a series of outliers of the Mines Group Formation, including Kwatebala Hill, embedded in the RAT. The general strike of the formations is east-west and the water-bearing layers of the RSC, plus SD and CMN may act as regions of preferential groundwater flow (SRK 1998).
- The South Aquifer – is located to the south of the Mambilima ridge. Very little information on this aquifer exists. Some groundwater is however associated with the various outliers and geological fragments as groundwater discharges at springs in the center and at the outlet of the Zakeo, sustaining the yield of the Konka River at 70 liters per second. West of the Konka River, the strike of the formations is generally east-west whereas it takes a southwest-northeast orientation east of the Konka. It is considered that groundwater flow is preferentially within the RSC in the outliers in a general northeast direction, then flows through fractures and openings in the RAT east of

the Fungurume Hill to join the Dipeta and North Aquifer in the area of Fungurume (SRK 1998).

- The Far North Aquifer – is located to the north of the Kwatebala Ridge and the Shanika Kundelungu Fragment and may be comprised of water-bearing layers of the RSC, SD, Dipeta and Mofia dolomites. Numerous springs have been identified, however the size and topographically-elevated location of this aquifer may limit the recharge potential in the vicinity of the proposed mining area.

4.4 WATER STRIKE DEPTHS

As part of the site characterization activities, Golder oversaw the drilling of 23 boreholes and the pump testing of seventeen boreholes by the end of 2006 (Table 4). The locations of all boreholes drilled are depicted in Figure 10. Boreholes designated by the prefix "TFWB" indicate Tenke-Fungurume Water Boreholes. Boreholes designated by the prefix "TFEB" indicate Tenke-Fungurume Environmental Boreholes. The satellite topography data were used to interpolate the borehole elevations based on the x and y coordinates of each borehole.

Water strike depths in boreholes drilled to date vary between five meters below ground level to 149 meters below ground level, as shown in Table 4.

4.5 GROUNDWATER ELEVATIONS AND FLOW DIRECTIONS

Groundwater levels were measured in the new and existing boreholes. The boreholes measured are shown in Figure 11 and the data are presented in Attachments 1 and 2. The water level elevation above mean sea level was obtained by using the DTM obtained from the satellite data. Figure 12 depicts the plot of groundwater elevation versus topography. The figure indicates that the groundwater elevation is generally correlated with topographic elevation – the higher the topographic elevation the higher the groundwater elevation. There are exceptions to this correlation that may be in response to the compartmentalization of the groundwater flow system by structural features as discussed in Section 4.3.

Table 4 Summary of Water Strike and Pump Test Information

				Pump Test Information																		General comments		
Borehole No.	GPS Co-ordinates UTM WGS 84		Elevation	Date testing commenced	Borehole depth measured by Test Crew	Pump Type	Pump installation depth	Static water level	Main observable WS	Avail. Drawdown for testing (m) (Main WS - SWL) or (Pump inlet depth - SWL)	SDT Discharge Rate					Duration of the steps	Constant Discharge Test				Remarks	Stratigraphy/ Lithology	Hydrogeology (BY = Blow Yield; WS = Water Strike)
	X	Y									Step 1	Step 2	Step 3	Step 4	Step 5		Duration	Abstraction rate	Drawdown at end of pumping period of CDT	Recovery Monitored			
			(mamsl)		(mbgl)		(mbgl)	(mbgl)	(mbgl)	(m)	(l/s)	(l/s)	(l/s)	(l/s)	(l/s)	(min)	(min)	(l/s)	(m)	(min)			
TFWB01A	411200	8830654	1429.12	09.10.2006 SDT 28.11.2006 CDT	163.92	Orbit 9002 BP 105	103 114	84.24	±80-85	18 29	3.6	6.2	12.6	24	-	3 x 60 +15	4320	20.8	1.64	1500	Test pumping completed. Recovery 99% in 1500minutes. TFWB02 monitored during CDT - no movement of Water Level.	Middle Roan Group - SD, RSC Formation - Siliceous, brecciated dolomite and dolomitic shale	WS at 80 mbgl assoc. with siliceous, cavernous and/or brecciated dolomite between No water and sample return.
TFWB02	411439	8831106	1417.24	03.10.2006	89.07	Orbit9602	84	65.41	87	18.59	4.4	7.5	15.5	35	-	4 x 60	4320	31.8	1.84	150	Test pumping completed. Recovery 100% in 150 minutes. TFWB01A monitored during CDT - no movement of Water Level.	Middle Roan Group - SD, RSC Formation - Siliceous, brecciated dolomite and dolomitic shale	WS at 89 mbgl assoc. with siliceous, cavernous and/or brecciated dolomite between 89 – 96 mbgl. BY = 5 l/s.
TFWB03A	409430	8831551	1368.83	08.11.2006	80.58	Orbit9602	49	20.57	67	28.43	4.8	8.4	16	33	-	4 x 60	7570	30.4	1.66	1500	Test pumping terminated prematurely due to broken bearing assembly on pump head. 65% recovery after 1500 minutes.	Middle Roan Group - SD Formation, brecciated, fractured and cavernous dolomite and dolomitic shale	WS with incr. BY from 24-67 mbgl assoc. highly fractured, cavernous and/or brecciated dolomite and dolomitic shale between 18 – 73 mbgl. BY = 60 l/s.
TFWB04	409746	8832994	1352.69	19.09.2006	150.7	Orbit 9002	63	17.05	37	20	3	6	12	24	-	3 x 60 +3	1540	13.8	23.81	500	Test pumping completed. Recovery 100% in 500 minutes.	Dipeta Subgroup - Sandstone and purple argillite.	1st WS at 37 mbgl associated with fractured dolomitic sandstone/ purple argellite contact. BY = 8-9 l/s. BY remained the same to EOH. Max. test yield greater than blow yield.
TFWB05	407027	8831503	1394.91	15.11.2006	148.25	Orbit 9002	80	9.48	73	70.52	3.5	6.5	13.5	20.5	-	4 x 60	3700	30.4	69	2400	Test pumping terminated prematurely due waterlevel reaching pump suction. 88% recovery after 1500 minutes.	Dipeta Subgroup - Limestone and purple argillite.	WS with incr. BY from 19-73 mbgl assoc. Fractured sandstone, siltstone and dolomite 19 - 78 mbgl. BY = 40 l/s.
TFWB06A	412380	8831244	1381.54	26.09.2006	146.1	Orbit 9602	120	12.14	54,101 &114	89.27	13	2-.2	30.5	36	-	4 x 60	4320	33.5	6.25	0.5	Test pumping completed. Recovery 100% in 0.5 minutes.	Dipeta Subgroup - Sandstone	1st major WS at 54 m (BY = 8 l/s). Fracture zone from 51 - 64. 2nd major fracture zone and water strike from 101 – 102 mbgl (BY incr. to 20.5 l/s). 3rd fracture zone and WS at 114 - 117 mbgl (BY incr. to approx. 65 l/s).

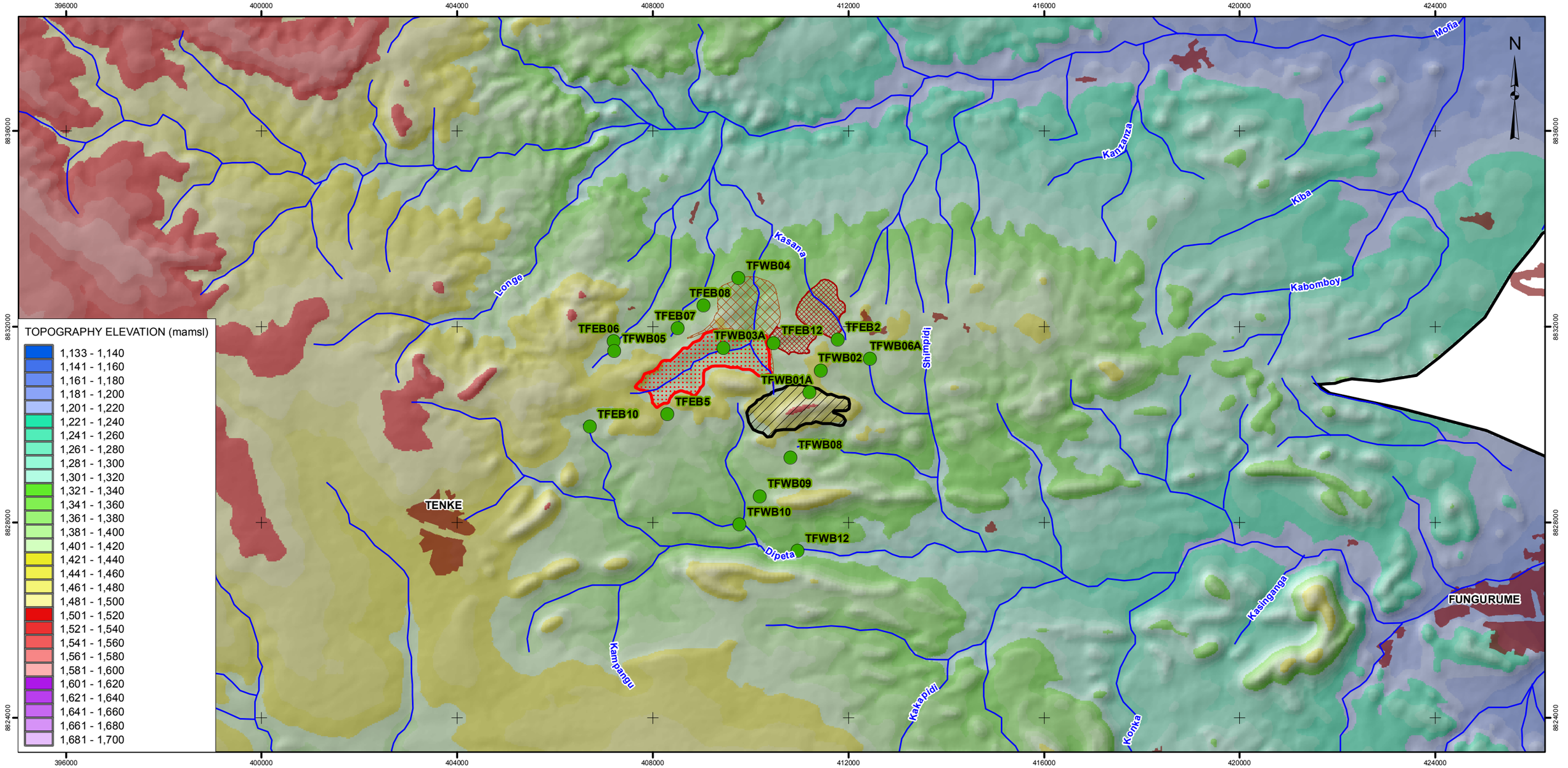
Table 4 Summary of Water Strike and Pump Test Information (continued)

				Pump Test Information																		General comments		
Borehole No.	GPS Co-ordinates UTM WGS 84		Elevation	Date testing commenced	Borehole depth measured by Test Crew	Pump Type	Pump installation depth	Static water level	Main observable WS	Avail. Drawdown for testing (m) (Main WS - SWL) or (Pump inlet depth - SWL)	SDT Discharge Rate					Duration of the steps	Constant Discharge Test				Remarks	Stratigraphy/ Lithology	Hydrogeology (BY = Blow Yield; WS = Water Strike)
	X	Y									Step 1	Step 2	Step 3	Step 4	Step 5		Duration	Abstraction rate	Drawdown at end of pumping period of CDT	Recovery Monitored			
			(mamsl)		(mbgl)		(mbgl)	(mbgl)	(mbgl)	(m)	(l/s)	(l/s)	(l/s)	(l/s)	(l/s)	(min)	(min)	(l/s)	(m)	(min)			
TFWB08	410808	8829328	1391.11	23.10.2006	137.1	Orbit 9002	110	71.18	78,115-117	32	5.2	9.5	14.1	-	-	3 x 60	1440	13.8	23.28	1440	Test pumping completed. 98% Recovery in 1440 minutes.	Middle Roan Group - CMN & SD Formation - Argillite & dolomite	1st major WS at 78 m (BY =? Loss of air). Fracture zone from 70 – 78 mbgl in dolomite. 2nd possible fracture zone and water strike from 115 – 124 mbgl (BY incr. to 12-16 l/s) in dolomite.
TFWB09	410181	8828539	1353.32	11.10.06	106.07	BP105	60	39.55	38 & 114	20.45	3.5	7.5	15.5	24	-	3 x 60 +1.5	4320	31	0.24	2	Test pumping completed. Recovery 100% in 2 minutes.	Middle Roan Group SD, RSC, RSF Formation - Cavernous, dolomite, sandstones and siltstones (mostly no sample and air return)	No return of sample/air during drilling from highly fractured to cavernous silty limestone/dolomite from 52 – 120 m
TFWB10	409763	8827958		31.10.06	113.01	Orbit 9602	81	23.97	39,51,57	33.03	4.2	8.4	16.3	31.8	-	4 x 60	4320	31.5	3.98	1500	Test pumping completed. 87% Recovery in 1500 minutes.	Dipeta Subgroup - Siltstone and sandstone.	1st significant WS at 39 m (BY =2-3 l/s). Fractured to highly fractured from 57 – 89 mbgl in siltstone/sandstone (BY incr. to 70-100 l/s).
TFWB12	410953	8827416	1307.51	17.10.06	147.08	Orbit9602	60	3.42	48,52 & 116	56.58	4.5	8.3	16.2	32.5	-	4 x 60	10080	30.3	8.32	1000	Test pumping completed. Recovery only approximately 87% after 1000 minutes.	Dipeta Subgroup - Siltstone and sandstone.	Very Shallow WS (BY = 6 l/s) in hydraulic continuity with Dipeta Stream associated with remnant alluvium. 2nd WS at 51 – 57 mbgl BY incr. from 8 l/s to 51 l/s associated 'voidal' or 'vuguey' siliceous dolomitic siltstone or mudstone. BY at 116mbgl incr. to >70 l/s associated with highly weathered and fractured zone between 106 and 114 mbgl.
CC1	423573.00	8835043.00	1181.99	20.11.06	112.78	Orbit9602	85	10.49	19-45	34.51	3	8.5	16.4	32.2	_	4 x 60	2900	30.5	1.8	1100	Test pumping completed. 100% Recovery after 1500 minutes.	Dipeta Subgroup - Limestone.	Borehole drilled unsupervised. Reported 1st WS at 19 mbgl increasing BY to approx. 45 mbgl. Final BY = 75 l/s

Table 4 Summary of Water Strike and Pump Test Information (continued)

				Pump Test Information																		General comments		
Borehole No.	GPS Co-ordinates UTM WGS 84		Elevation	Date testing commenced	Borehole depth measured by Test Crew	Pump Type	Pump installation depth	Static water level	Main observable WS	Avail. Drawdown for testing (m) (Main WS - SWL) or (Pump inlet depth - SWL)	SDT Discharge Rate					Duration of the steps	Constant Discharge Test				Remarks	Stratigraphy/ Lithology	Hydrogeology (BY = Blow Yield; WS = Water Strike)
	X	Y									Step 1	Step 2	Step 3	Step 4	Step 5		Duration	Abstraction rate	Drawdown at end of pumping period of CDT	Recovery Monitored			
			(mamsl)		(mbgl)		(mbgl)	(mbgl)	(mbgl)	(m)	(l/s)	(l/s)	(l/s)	(l/s)	(l/s)	(min)	(min)	(l/s)	(m)	(min)			
CC2	424276.00	8835658.00	1183.57	24.11.06	115	BP105	100	12.46	46	33.54	4.7	8.8	15.5	20.2	-	4 x 60	1320	8.7	82.74	1500	Test pumping terminated prematurely due waterlevel reaching pump suction. 88% recovery after 1500 minutes.	Dipeta/Mwashia Subgroups	Borehole drilled unsupervised. Final BY = 2 l/s
TFEB02	411782	8831730	1396.38	29.11.06	30.42	BP30	26	8.65	24	15.44	0.6	1	2	4	-	3 x 60 + 4	1350	1.5	15.98	1500	Test pumping terminated prematurely due waterlevel reaching pump suction. 95% recovery after 1500 minutes.	Dipeta Subgroup - Limetone and sandstone	WS at 16 mbgl. BY = <0.5 l/s. Associated with highly weathered, fractured and cvernous limestone. 2nd WS at 24 mbgl (BY = 2-3l /s) in fractured sandstone..
TFEB03	412364	8830869	1379.41	26.11.06	117.81	BP30	71	50.93	-	20.07	-	-	-	-	-	-	51	0.4	60.36	150	Test pumping terminated prematurely due waterlevel reaching pump suction. 60% recovery after 150 minutes.	Possibly Mwashia or Lower Kundelungu, chloritic schists.	No WS measured. Seapage into soft but solid chloritic schist.
TFEB08	409032	8832439	1365.79	04.11.06	49.8	Orbit 9002	48	29.53	36,42	12.47	3.2	6.5	12.6	25	-	4 x 60	1440	21.5	0.33	6	Test pumping completed. Recovery 100% in 6 minutes.	Dipeta Subgroup - Siltstone and sandstone.	1st WS at 36 m (BY =2-3 l/s) in fractured sandstone with caveties below.
TFEB09	412150	8829435	1341.92	21.11.06	119.97	Orbit 9002	81	20.96	69	48.04	1.3	1.8	3	4	-	3 x 60 + 7	1440	2	21	1440	Test pumping completed. Recovery 100% in 1500 minutes.	Dipeta Subgroup - Siltstone and sandstone.	WS at 69 mbgl. BY = 2-3 l/s. Associated with slightly weathered and fractured argellite.
TFEB10	406617	8830034	1390.78	23.09.2006	84.82	Orbit 9002	78	40.00	61	24.2	3	8	16	21	26	4 x 60+20	1440	20.8	0.36	0.5	Test pumping completed. Recovery 100% in 0.5 minutes. Water sample collected by bailing on 27.11.2006	Dipeta Subgroup - Argillite & cavernous dolomite	WS at 61 mbgl. BY = 10-11l/s. Associated with highly fractured purple argellite followed by cavities and loss of air below to approx. 81 mbgl. Max. test yield much greater than BY.

_Projects\Temp Tenke\Maps\Modelling Jan 2007\Drilled Boreholes Jan 2007.mxd _Projects\Temp Tenke\PDF's\2007\Modelling Jan 2007\Drilled Boreholes Jan 2007.pdf



LÉGENDE / LEGEND

- DRILLED BOREHOLE
- RIVER
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

1 0 1 2 3 4 5 6

ÉCHELLE 1:80,000 KILOMÈTRES
SCALE 1:80,000 KILOMETRES

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

LOCATION OF BOREHOLES DRILLED BY GOLDER TO END OF OCTOBER 2006

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	XX	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	HvR	30 Jan 2007		

FIGURE: 10

_Projects\Temp Tenke\Maps\Modelling Jan 2007\Water level Boreholes Jan 2007.mxd _Projects\Temp Tenke\PDF's\2007\Modelling Jan 2007\Water level Boreholes Jan 2007.pdf

396000 400000 404000 408000 412000 416000 420000 424000

8836000 8832000 8828000 8824000

Mofia

Kiba

N

TFWB04
TFEB08
TFEB07
TFEB06
TFWB05
TFM6
TFEB12
TFEB2
TFWB06A
TFM5
TFWB2
THG3
TFWB01A
TFEB5
TFEB10
TFM4
TFWB08
TFWB09
TENKE
TFWB10
TFWB12
TFM3
FUNGURUME
TFM1

TOPOGRAPHY ELEVATION (mamsl)

- 1,133 - 1,140
- 1,141 - 1,160
- 1,161 - 1,180
- 1,181 - 1,200
- 1,201 - 1,220
- 1,221 - 1,240
- 1,241 - 1,260
- 1,261 - 1,280
- 1,281 - 1,300
- 1,301 - 1,320
- 1,321 - 1,340
- 1,341 - 1,360
- 1,361 - 1,380
- 1,381 - 1,400
- 1,401 - 1,420
- 1,421 - 1,440
- 1,441 - 1,460
- 1,461 - 1,480
- 1,481 - 1,500
- 1,501 - 1,520
- 1,521 - 1,540
- 1,541 - 1,560
- 1,561 - 1,580
- 1,581 - 1,600
- 1,601 - 1,620
- 1,621 - 1,640
- 1,641 - 1,660
- 1,661 - 1,680
- 1,681 - 1,700

396000 400000 404000 408000 412000 416000 420000 424000

LÉGENDE / LEGEND

- BOREHOLE WITH WATER LEVEL
- RIVER
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

1 0 1 2 3 4 5 6

ÉCHELLE 1:80,000 KILOMÈTRES
SCALE 1:80,000 KILOMETRES

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

BOREHOLES WITH GROUNDWATER LEVEL DATA

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035		ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

FIGURE: 11

Figure 12 **Correlation Between Groundwater Level and Topographic Elevations at Boreholes**

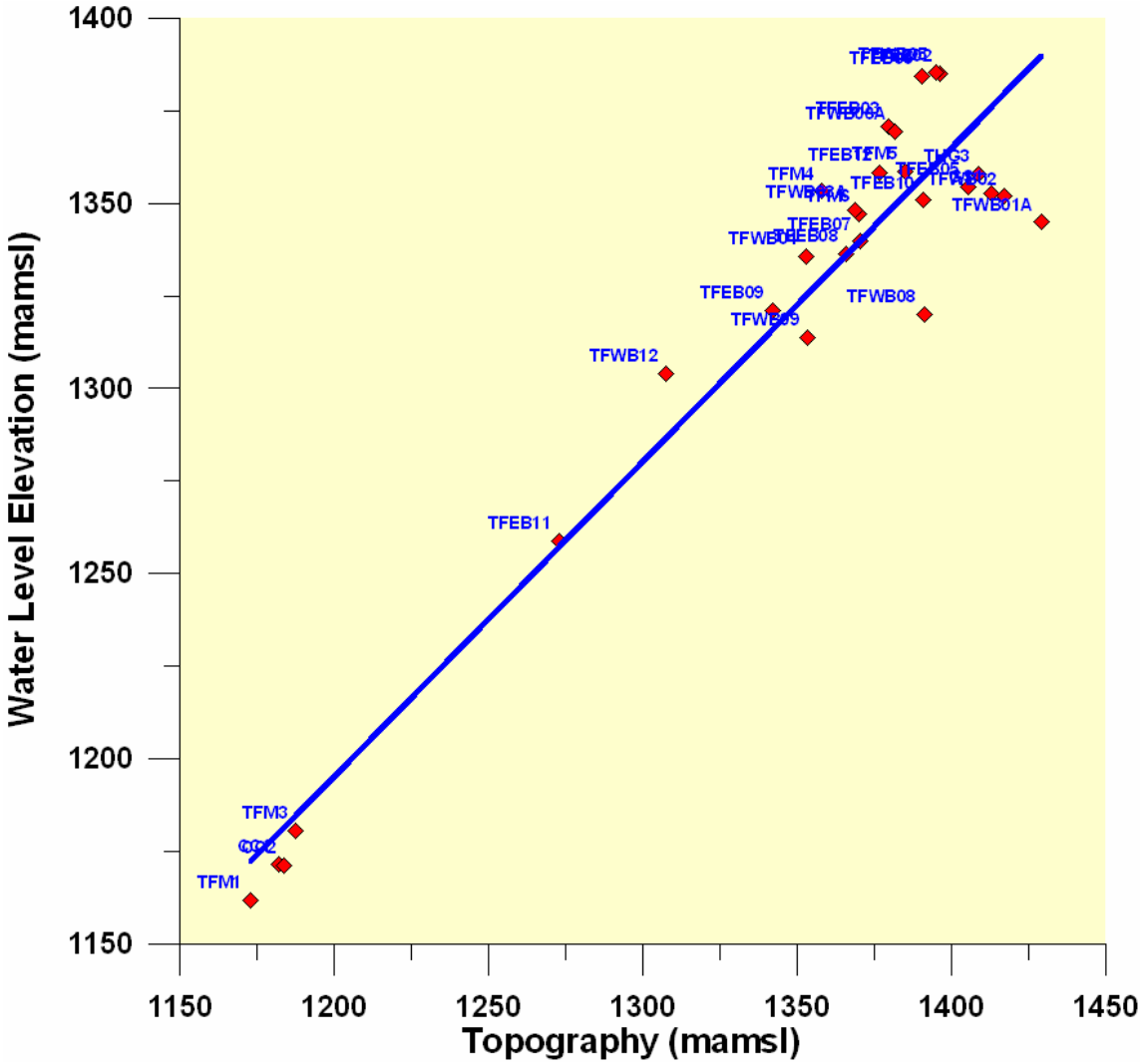


Figure 13 depicts the groundwater elevations and generalized groundwater flow directions. There are large differences in groundwater elevations over short distances in the vicinity of the Project area making interpretation of the data and the drawing of lines of equal groundwater elevation (piezometric contours) problematic. The localized differences in groundwater elevation are more than likely the result of the compartmentalisation of the groundwater flow system by structural features. This phenomenon is typically observed in dolomitic (karst) terrain where high transmissivity geological units are juxtaposed with low transmissivity units and groundwater flow occurs preferentially in the more permeable units. Groundwater flow between compartments is often limited because of truncation of the high transmissivity units.

Figure 14 provides an interpreted groundwater elevation contour map constructed from the elevations presented in Figure 12 and Figure 13 and indicates that the local east west groundwater divide lies to the north of the proposed Kwatebala pit. In general, according to the groundwater elevations, flow occurs from the mine site northwards towards the Mofia River and southwards toward the Dipeta River.

4.6 HYDRAULIC TESTING AND PARAMETERS

Aquifer tests were conducted in November and December 2006 on 17 of the new boreholes. Each borehole was tested to:

- Determine the transmissivity of the aquifer.
- Collect water samples for chemical analysis.

Details of the pumping tests are given in Table 4 and the results summarized in Table 5. Attachment 3 presents the pumping test hydrographs. Water quality data from the test wells are presented in Attachment 4.

4.6.1 Transmissivity

Transmissivity is defined as the rate of flow of water in cubic meters per day through a unit width under a unit hydraulic gradient (units: cubic meters/day/meters or square meters/day). Estimates of the transmissivity of the main water-bearing units (aquifers) were obtained from the results of constant discharge pumping tests conducted by Golder during the field exploration program.

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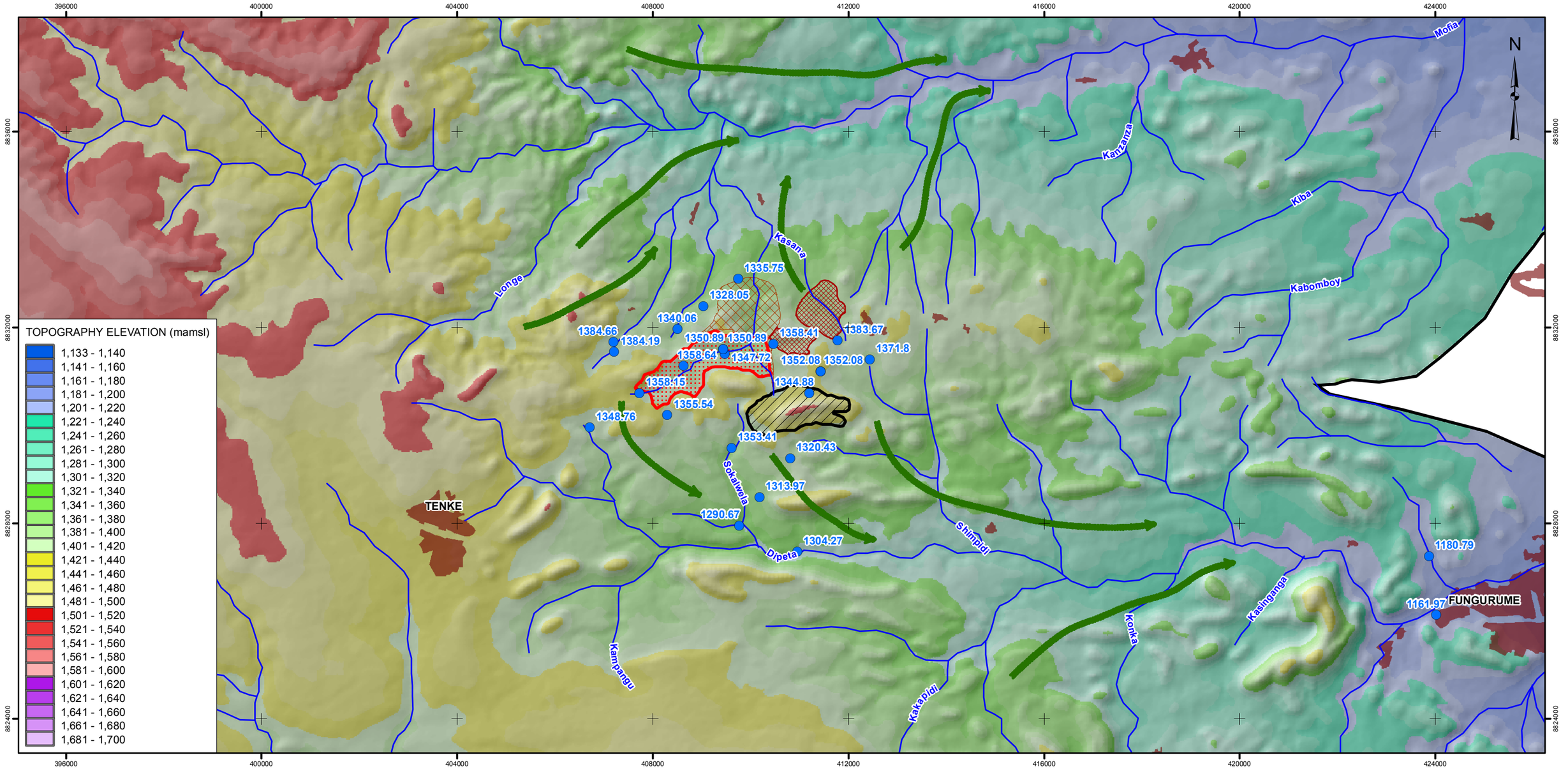

LÉGENDE / LEGEND

- BOREHOLE WITH WATER LEVEL
- GROUNDWATER FLOW DIRECTION
- RIVER
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

1 0 1 2 3 4 5 6

ÉCHELLE 1:80,000 KILOMÈTRES
SCALE 1:80,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

WATER LEVEL ELEVATION AND POSTULATED GROUNDWATER FLOW DIRECTION

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 13

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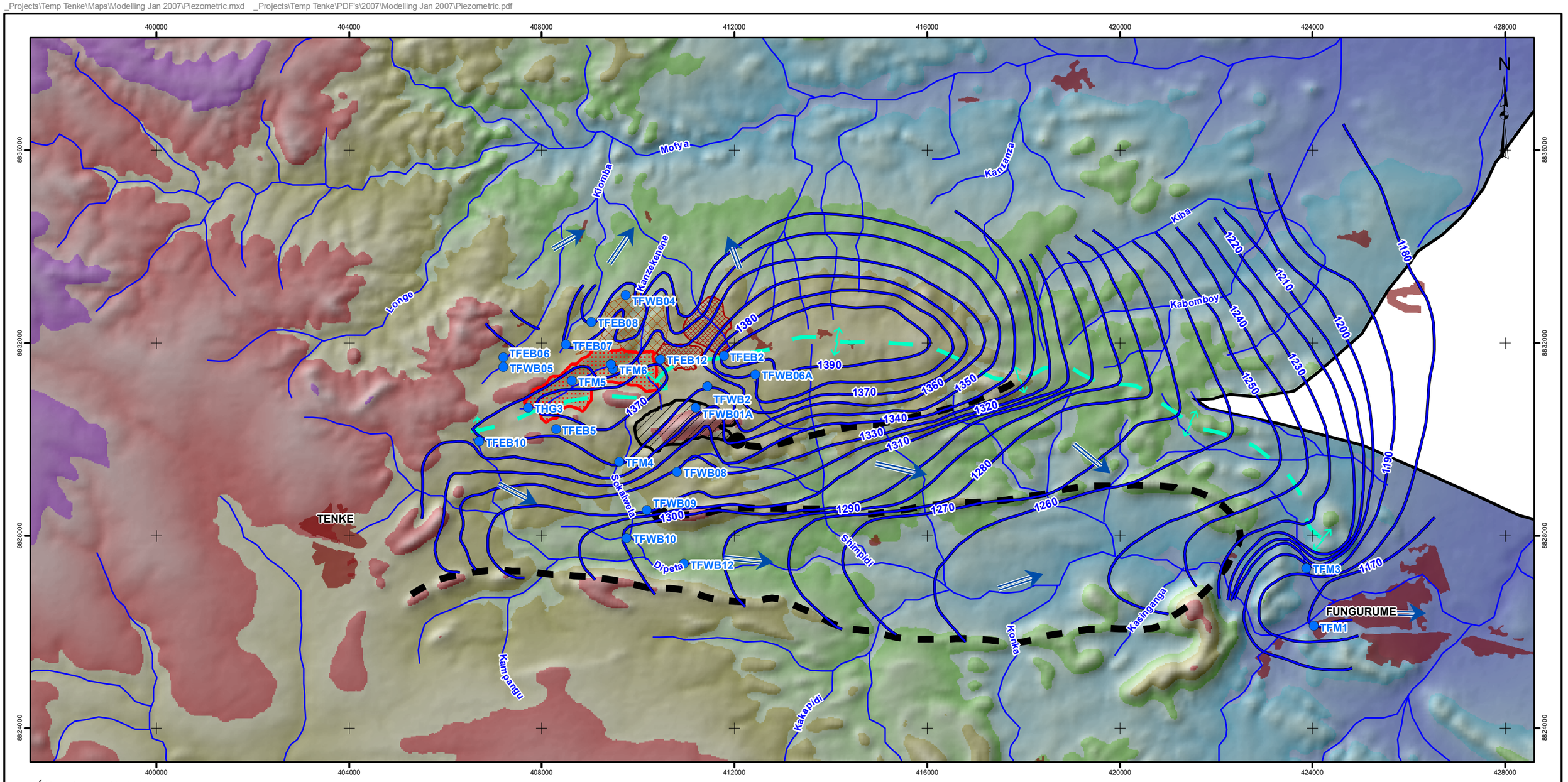


LÉGENDE / LEGEND

- BOREHOLE WITH WATER LEVEL
- SENS D'ÉCOULEMENT D'EAUX SOUTERRAINES/GROUNDWATER FLOW DIRECTION
- GROUNDWATER ELEVATION CONTOUR (mamsl)
- LIGNE DE PARTAGE EXTÉRIEURE/SURFACE WATERSHED
- FRONTIÈRE PERMÉABLE DE COUCHE AQUIFÈRE/LEAKY AQUIFER BOUNDARY
- RIVER
- MODELLED AREA
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK

TOPOGRAPHY ELEVATION (mamsl)

Value

1695

1132

1 0 1 2 3 4 5 6

ÉCHELLE 1:80,000 KILOMÈTRES
SCALE 1:80,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

INTERPRETED GROUNDWATER LEVEL ELEVATIONS AND FLOW DIRECTIONS CURRENT CONDITIONS

PRÉLIMINAIRE / DRAFT

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 14

Pumping tests were analysed using different methods of evaluation suitable for the specific geological conditions. Table 5 provides the results from the pumping test data. The time-drawdown graphs are depicted in Attachment 3. The heterogeneity of the aquifer(s) is evident from the variability in the calculated transmissivity values. This behavior is typical for karstic, fractured and weathered hard rock aquifers.

4.6.2 Hydraulic Conductivity

Hydraulic conductivity is defined as the rate of flow of water in cubic meters per day through a cross section of one square meter under a unit hydraulic gradient (units: cubic meters/day/square meters or meters/day). Estimates of the hydraulic conductivity of the water-bearing units are obtained through model calibration (Section 7.5.3).

4.6.3 Storativity

Storativity is defined as the volume of water an aquifer release from or takes into storage per unit surface area of the aquifer per unit change in head. Storativity is the specific storage (So) times aquifer thickness (B).

Specific yield is the volume of water an aquifer releases from storage per unit surface area of the aquifer per unit change in head under gravity.

Since the pumping tests were single-well tests (without an observation well), values of the storage coefficient and/or specific yield cannot be determined. Experience indicates that specific yield values for the lithologies at Tenke will likely be in the range of one to six percent.

4.6.4 Porosity and Effective Porosity

Porosity is the volume of voids to the total volume of rock mass. Porosity includes all pores and fractures in the rock whether or not they are interconnected. Porosities for fractured rocks similar to those at Tenke range from less than 1 percent to up to 30 percent.

Effective porosity represents the volume of interconnected voids to the total volume of the rock mass. In the sedimentary rocks at Tenke, effective porosity is represented by the interconnected fractures that occupy a small proportion of the total porosity. Effective porosity is likely in the range of one to five percent.

Table 5 Transmissivity From Pumping Tests Conducted by Golder

Borehole	Transmissivity Cooper-Jacob Analysis (m^2/d)	Transmissivity Theis Recovery Analysis (m^2/d)	Aquifer Lithology	Saturated Thickness (m)
TFEB 02	14	4	fractured dolomite/limestone	9
TFEB 03	0.15	0.2	schist/sandstone	-
TFEB 08	6,500	7,800	fractured sandstone and dolomite/limestone	18
TFEB 09	25	5.7	fractured sandstone	2
TFEB10	4,950	instantaneous recovery	highly fractured purple argillite followed by cavities	>23
TFWB01A	1,350	1,400	fractured dolomitic shales and dolomite	>80
TFWB02	4,000	3,250	siliceous, cavernous and brecciated dolomite	>23
TFWB03A	4,810	2,000	fractured dolomitic shales and dolomite	>60
TFWB04	181	179	fractured interbedded dolomite and sandstone	8
TFWB05	165	28	fractured dolomite/limestone and fractured sandstone	75
TFWB06A	4,290	instantaneous recovery	fractured sandstone with interbedded dolomite	63
TFWB08	170	264	fractured dolomite and dolomitic shale	8
TFWB09	5,040	instantaneous recovery	cavernous dolomite	>82
TFWB 10	1,350	976	fractured sandstone and siltstone	75
TFWB12	269	229	siliceous highly fractured interbedded dolomite, siltstone and mudstone	>68

5 CONCEPTUAL MODEL

The first step in the modeling process is the construction of a conceptual model of the groundwater flow system and determination of the model domain. The conceptual model consists of a set of assumptions that reduce the actual groundwater conditions within the model domain to simplified versions that are acceptable in view of the modeling objectives and available data.

5.1 KEY CONCEPTS

The nature and distribution of the geological units and the geological structures control the hydrogeology of the study area. The primary geological feature in the regional study area is the Dipeta syncline. The Dipeta syncline extends approximately two kilometers from north to south and 16 kilometers from east to west. The Dipeta syncline is relatively near surface in the eastern part of the regional study area and dips gently westward. Contained within the Dipeta syncline is a geological sequence consisting of dolomite, sandstone and shale with a variable range transmissivity, as shown in Table 5.

Within the Dipeta syncline, the primary hydrostratigraphic unit is the dolomitic aquifer. The aquifer is comprised of a thick sequence of up to 615 meters of weathered siliceous or massive dolomite separated by sandstone. Geologically, the top of the aquifer is defined by the Upper Mwashia Group (R4) and Kundelungu Supergroup consisting of siliceous silt and sandstone. The base of the dolomitic aquifer is the RAT (R1). The localized lateral boundaries of the aquifer are provided by structural features (for example, anticlines and synclines) that disrupt the lateral continuity of the dolomitic aquifer. This combination of dolomitic aquifer disrupted by structural features has resulted in a compartmentalization of groundwater systems.

Because of the regional dip of the syncline to the west, the dolomitic aquifer is narrower and is found closer to the surface in the eastern part of the regional study area than in the western part. To the west the dolomitic aquifer appears to narrow between Kwatebala and Tenke and then close in the vicinity of Tenke. Further west it may widen and form a separate compartment (SRK 1998).

The dolomitic aquifer is divided into an upper and lower aquifer. The upper dolomitic aquifer consists of the Mwashya and Dipeta Group. The lower dolomitic aquifer consists of the CMN, SD, RSC and RSF formations (SRK 1998). The division between the upper and lower parts of the dolomitic aquifer is the less permeable sandstone of the RGS.

The dolomitic aquifer is moderately to highly permeable depending on the degree of weathering, fracturing and development of solution cavities. Highest permeabilities are found in areas of solution cavities (karst). The estimated transmissivity for the dolomitic aquifer ranges from about 200 to 5,000 square meters per day, as indicated by the aquifer test analysis (Table 5). The aquifer is anisotropic with highest permeabilities orientated parallel to the axis of the Dipeta syncline (east-west) and lowest permeabilities perpendicular to the syncline.

Recharge to the dolomitic aquifer is from precipitation during the rainy season over the outcrop area of the dolomitic aquifer and from the infiltration of surface water where the water table is below the river bed elevation. The annual recharge is estimated to be in the order of 240 millimeters per year.

Groundwater flow is interpreted to be preferentially through the dolomitic aquifer. The most permeable features such as the weathered siliceous or massive dolomite with karstic features would convey the majority of the groundwater flow. There would be less groundwater flow through the dolomitic shale, sandstone and siltstone because of the lower permeabilities of these units. These lithologies would act primarily as low-permeability boundaries to groundwater flow. Groundwater flow in these units occurs where significant fractures and faults are found.

Groundwater flow is from areas of higher piezometric elevations to lower piezometric elevations. The highest groundwater elevations are found locally in the area of the proposed plant site to the northeast of the proposed Kwatebala pit (Figure 14). This area also appears to be located overlying a groundwater divide separating groundwater flow moving northward toward the Mofia River and flow southward toward the Dipeta River.

Groundwater flow converges toward and in part discharges to the Dipeta River and flows eastward under a hydraulic gradient of about 0.023 (Figure 14). Because the dolomite aquifer narrows and shallows to the east, groundwater is forced to the surface discharging into the Dipeta River providing year-round baseflow. Elsewhere, discharge from the dolomitic aquifers is to various springs or streams, which flow towards the Dipeta River.

5.2 GROUNDWATER SYSTEM GEOMETRY

As a result of the local topographic and geological conditions and a general high correlation between groundwater elevations and topographic elevation (Figure 12), groundwater divides occur approximately beneath the major surface

water divides (watershed boundaries). The groundwater elevation data indicate groundwater flow (depicted in Figures 13 and 14) and discharge to the lower elevations of localized drainages. It is therefore appropriate to include the total areas of the surface water catchment areas of both the Mofia and Dipeta rivers into the modeling domain since the proposed mining infrastructure straddles the surface water divide between these two catchments. In addition, a third sub-catchment of the Tshilongo River to the west of the Dipeta and Mofia river catchments was included in the model domain in order to determine the potential for mining to affect this catchment (Figure 3).

The vertical extent of the groundwater system is not certain. Boreholes drilled by Golder do not exceed a total depth of 150 meters below surface. Water strikes occur readily down to this depth. It was estimated by SRK (1998) that the dolomitic aquifer may be comprised of a thick sequence of up to 615 meters of weathered siliceous or massive dolomite separated by sandstone. In this study it is assumed that the dolomitic aquifer is on average at least 450 meters thick. Based on the drilling results obtained by Golder thus far, and data from SRK (1998), this thickness is probably a reasonable estimate of total aquifer thickness. This thickness is greater than the estimated total mine pit depth of 150 meters. Furthermore, model calibration involves comparison to observed groundwater elevations which are a function of the product of the saturated aquifer thickness and the hydraulic conductivity (transmissivity), groundwater recharge and boundary conditions. The calibration process will therefore result in an "effective transmissivity" for the overall groundwater flow system independent of thickness.

5.3 SYSTEM BOUNDARIES

Boundaries of the numerical model were chosen to reflect the geometry of the groundwater system as described above. The boundaries around the perimeter of the model were chosen to conform to groundwater divides (no-flow boundaries) that are interpreted to be present beneath the major surface water divides, consistent with standard modeling practice. The model domain was chosen based on topographical control. The base of the model domain was chosen to be 450 meters below ground surface throughout the model area. Section 6 provides a detailed discussion of the boundary conditions and rationale for their selection.

5.4 HYDRAULIC PROPERTIES

In a typical hydrogeological setting, groundwater flow is closely linked to the topography, geology and structural geology of an area. There is no reason to believe that the area under investigation will not conform to this assumption and

therefore the surface expression of the geology as depicted in Figure 7 forms the basis on which the conceptual hydrogeological model has been developed. From the limited available pumping tests conducted across the study area in the boreholes drilled (0 to 150 meters below surface), it is evident that hydraulic conductivity values (transmissivity) may vary by orders of magnitude both spatially and with depth. There is evidence from the geotechnical drilling conducted to suggest that a zone of lower transmissivity representing the oxidized/weathered zone is present (Golder 2006). There is, however, no evidence to suggest that hydraulic conductivity necessarily decreases with depth from the groundwater exploration drilling. The geological setting is also extremely complex as a result of the folding and thrusting which may be enhancing development of high hydraulic conductivity zones (Figures 8 and 9).

The major hydrostratigraphic units of probably different hydraulic properties that exist within the study area are:

- Geologically, the top of the aquifer is defined by the Upper Mwashia Group (R4) and Kundelungu Supergroup consisting of siliceous silt and sandstone.
- The dolomitic aquifer within the Dipeta syncline which is the primary hydrostratigraphic unit. The aquifer is comprised of a thick sequence of up to 615 meters of weathered siliceous or massive dolomite interbedded by sandstone and lower permeability mudstone and argillaceous horizons.
- The base of the dolomitic aquifer is the RAT (R1).

Localized boundaries of the dolomitic aquifer are provided by structural features (for example, anticlines and synclines as shown on Figures 8 and 9) that disrupt the lateral continuity of the geological sequence. This combination of dolomitic aquifer disrupted by structural features has resulted in a compartmentalization of groundwater systems with high permeability units juxtaposed with low permeability units.

At this time, it is not possible to determine hydraulic properties for the individual geological units that make up the dolomitic aquifer system because of the complexity of the geological setting and limited investigation program. It is however recognized that the dolomitic aquifer forms a unit capable of transmitting and storing large quantities of groundwater.

5.5 RECHARGE, DISCHARGE AND DIRECTIONS OF FLOW

The groundwater system within the study area is largely recharged via infiltration of precipitation. Other future sources of recharge will include seepage from stockpiles and waste rock facilities. Very little (negligible) seepage is expected to occur from the tailings storage facility because it will be a fully-lined facility.

Most of the groundwater recharge occurring within the study area discharges internally to the surface drainage systems via springs and discharge to the base of river drainage systems (Section 2.4.2).

6 APPROACH TO NUMERICAL MODELING

A numerical model was constructed to represent the conceptual groundwater system of the study area as presented above. The purpose of the model is to develop a tool that can be used to assess the potential groundwater conditions under a variety of mining and post-mining conditions. The objectives of the modeling include:

1 Determination of the inflow rates over time into the open pit during mining.
2 Determination of the extent of the cone of depression associated with pit dewatering and changes in groundwater levels in local wells and springs.
3 Determination of the effects of pit dewatering on baseflow discharge to surface water.
4 Determination of the pathways of seepage from the waste rock stockpiles and waste rock facilities.
5 Determination of the effects of pumping the wells for mine water supply.
6 Determination of the post-closure groundwater flow regime following the end of mining and pit flooding.

6.1 SOFTWARE SELECTION

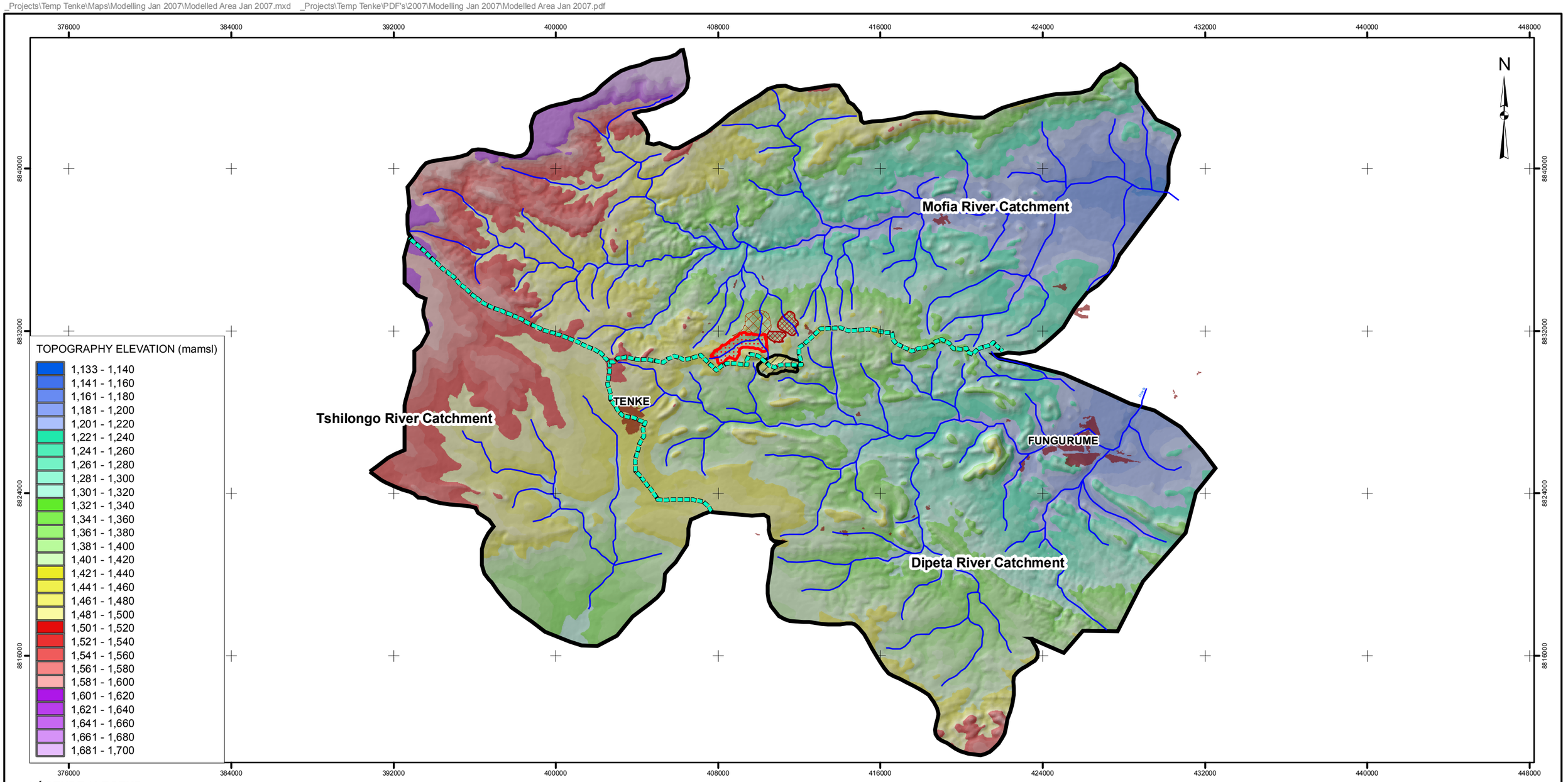
The code selected for conducting the modeling of the Tenke-Fungurume study area is FEFLOW developed by the WASY Institute for Water Resources Planning and Systems Research, Ltd. Berlin, Germany (Diersch 1979). FEFLOW is an interactive groundwater modeling system for three and two-dimensional, areal and cross-sectional, fluid density-coupled, thermohaline or uncoupled, variably saturated, transient or steady state flow, mass and heat transport in subsurface water resources with or without one or multiple free surfaces.

FEFLOW is used worldwide as a groundwater-modeling tool at universities, research institutes, government offices and engineering companies.

6.2 MODEL AREA

The model area is presented on Figure 15 and includes the Mofia, Dipeta and part of the Tshilongo sub-catchment. The model area was selected through trial-and-error to ensure that the effects of dewatering did not extend to the model boundaries.

_Projects\Temp Tenke\Maps\Modelling Jan 2007\Modelled Area Jan 2007.mxd _Projects\Temp Tenke\PDF's\2007\Modelling Jan 2007\Modelled Area Jan 2007.pdf



LÉGENDE / LEGEND

- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- CATCHMENT DIVIDE
- RIVER

3 0 3 6 9 12 15

ÉCHELLE 1:190,000KILOMÈTRES
SCALE 1:190,000KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

MODEL AREA

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ REVIEW	DB	30 Jan 2007		

FIGURE: 15

The area depicted in Figure 15 comprises an area of approximately 905 square kilometers. During the selection of the modeling domain the area was kept as small as possible because groundwater level data and data on hydrogeological properties are not available in areas outside the immediate Kwatebala pit area.

6.3 NUMERICAL FLOW MODEL

A steady state groundwater flow model for the study area was constructed to simulate undisturbed groundwater flow conditions. These conditions serve as starting heads for the transient simulations of groundwater flow where the effect of abstracting water from the system for pit dewatering will be taken into consideration.

The simulation model (FEFLOW) used in this modeling study is based on three-dimensional groundwater flow and may be described by the following equation:

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) \pm W = S \frac{\partial h}{\partial t} \qquad (1)$$

where

h = hydraulic head [L]

Kx,Ky,Kz = Hydraulic Conductivity [L/T]

S = storage coefficient

t = time [T]

W = source (recharge) or sink (pumping) per unit area [L/T]

x,y,z = spatial co-ordinates [L]

6.4 MODEL BOUNDARIES

Boundary conditions express the way the model domain interacts with its environment. In other words, they express the conditions of known groundwater flux, or known variables, such as piezometric head. Different boundary conditions result in different model solutions hence the importance of stating the correct boundary conditions. Boundary conditions in a groundwater flow model can be specified either as:

- Dirichlet Type (or constant head) boundary conditions.
- Neuman Type (or specified flux) boundary conditions.
- A mixture of the above.

6.5 MODEL PERIMETER BOUNDARIES

Groundwater flow directions largely mimic topography (Figures 12 and 14) being perpendicular to topographic contours and the groundwater basin geometry can be approximated by the surface water drainage geometry. The boundaries of the numerical model are shown on Figure 15. The entire model area perimeter coincides with the assumed locations of groundwater divides. Since by definition, groundwater does not cross from one side of these divides to the other, they are represented numerically by what is referred to as a "no-flow" boundary condition (zero specified flux Neuman Type II boundary condition).

6.5.1 Internal Model Boundaries

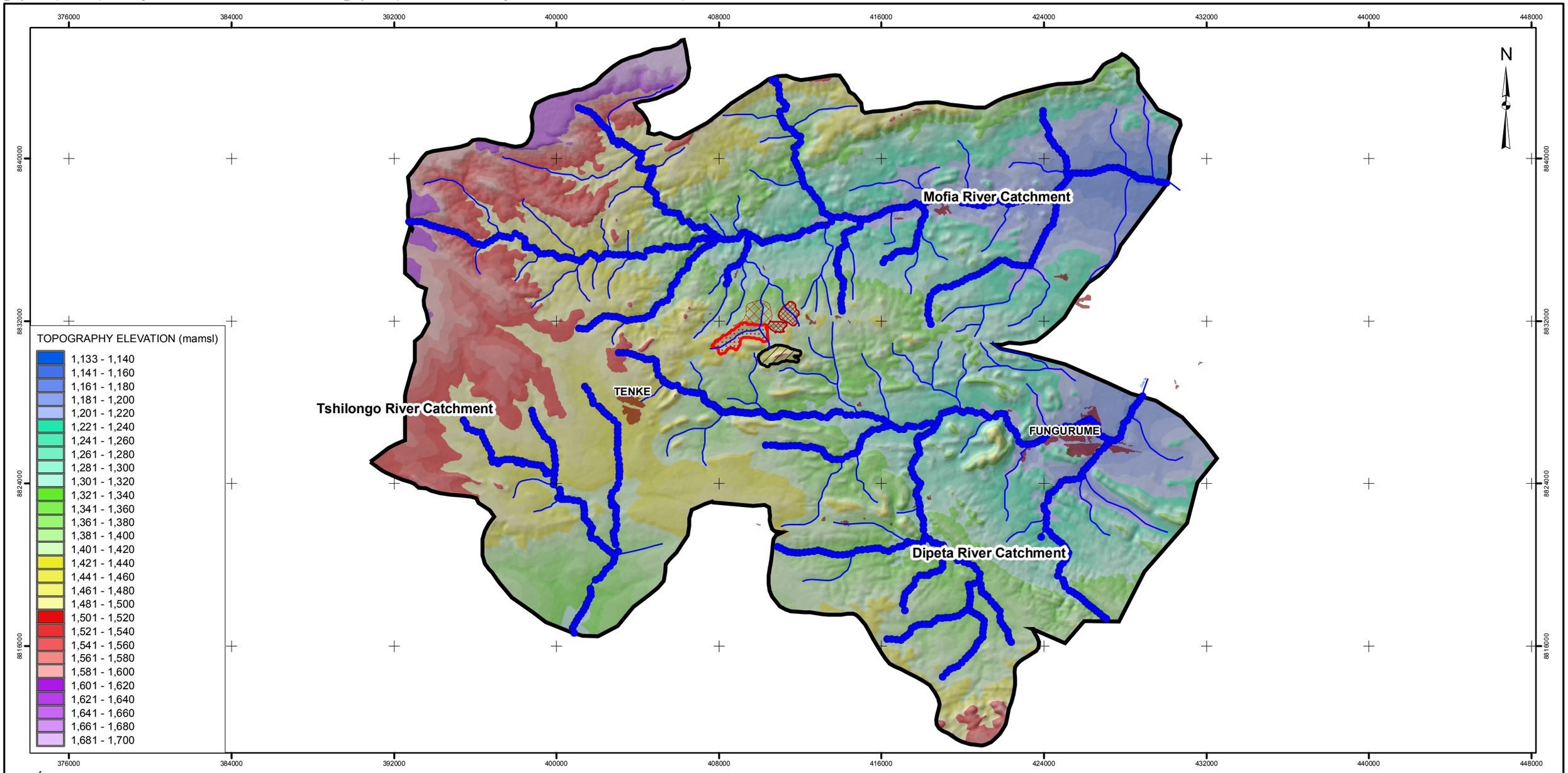
The groundwater system within the study area is largely recharged via infiltration of precipitation. It is thought that most of the groundwater recharge occurring within the study area discharges internally to the surface drainage systems via springs and discharge to river drainage systems (baseflow). Constant head boundary conditions were therefore specified along some of the major surface drainages which are known to receive baseflow from groundwater as indicated on Figure 16. Drainages not shown as constant drain head have little if any perennial flow and only flow during storm events.

The constant head boundary condition along river drainage systems allows groundwater to discharge, in this case, from the model area at a rate dependent on the hydraulic conductivity and hydraulic gradient across the boundary. The constant head boundaries were constrained so that water can only be removed from the system – a reversal of the hydraulic gradient back towards the aquifer from the surface system (as might be occurring during pit dewatering) would therefore not allow water to enter the aquifer from the surface water system. This therefore represents a true "drain type" boundary condition.

6.5.2 Model Base Boundary Condition

The model domain was assumed to extend vertically to a depth of 450 meters. It is assumed that the base of the model is impermeable (a no-flow boundary).

_Projects\Temp Tenke\Maps\Modelling Jan 2007\Constant head boundaries Jan 2007.mxd _Projects\Temp Tenke\PDF's\2007\Modelling Jan 2007\Constant head boundaries Jan 2007.pdf



LÉGENDE / LEGEND

- DRAIN HEADS BOUNDARIES
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

LOCATION OF INTERNAL MODEL DRAIN BOUNDARIES

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ REVIEW	HvR	30 Jan 2007		

FIGURE: 16

6.5.3 Model Surface Boundary Condition

Boundary conditions applied to the top surface area of the model include the following:

- A defined quantity of background recharge (240 millimeters per year) is assigned to the entire surface area for the pre-mining steady state simulation (calibration).
- For the mining phase a similar recharge rate was assigned to the entire surface area except for the tailings storage facility (0 millimeters per year because it will be lined).
- Natural aquifer recharge (240 millimeters per year) is assumed across the stockpiles and waste rock facilities.
- For the post-closure situation the natural recharge to the exposed rock in the pit area was increased to 40 percent of MAP (i.e., 480 millimeters per year). This was to take account of the lack of evaporation from the exposed rock in the pit area.

6.5.4 Representation of Groundwater Flow

Based on the geological and hydrogeological conditions, a simplified groundwater flow model was constructed consisting of three active layers:

- Layer 1 – the upper 50 meters below ground surface representative of weathered/oxidized material.
- Layer 2 – From 50 meters to 150 meters below ground surface to allow representation of the dolomitic aquifer system over the pit depth.
- Layer 3 – from 150 meters to 450 meters below ground surface to represent the geological conditions to the base of the dolomitic aquifer system.

6.6 HYDROGEOLOGICAL UNITS

The geologic formations of the study area are discussed in Section 3. These formations were grouped into hydrostratigraphic units of similar hydraulic properties, lithology and depositional history. Using these groupings and the geometry of the formations interpreted from the geologic maps and cross sections, zones of similar hydraulic properties were defined in the model. Figure 17 shows the surface expression of the assigned hydrostratigraphic units in the form of an initial hydraulic conductivity distribution for Layer 1 of the model. The hydraulic conductivity distribution for Layer 1 has been extended into Layers 2 and 3. The variability in the flow between the layers is provided by the variation in the transmissivity of each layer due to the different thicknesses assigned to the layers (see Table 7, Section 7.5.3).

6.7 HYDRAULIC STRESSES

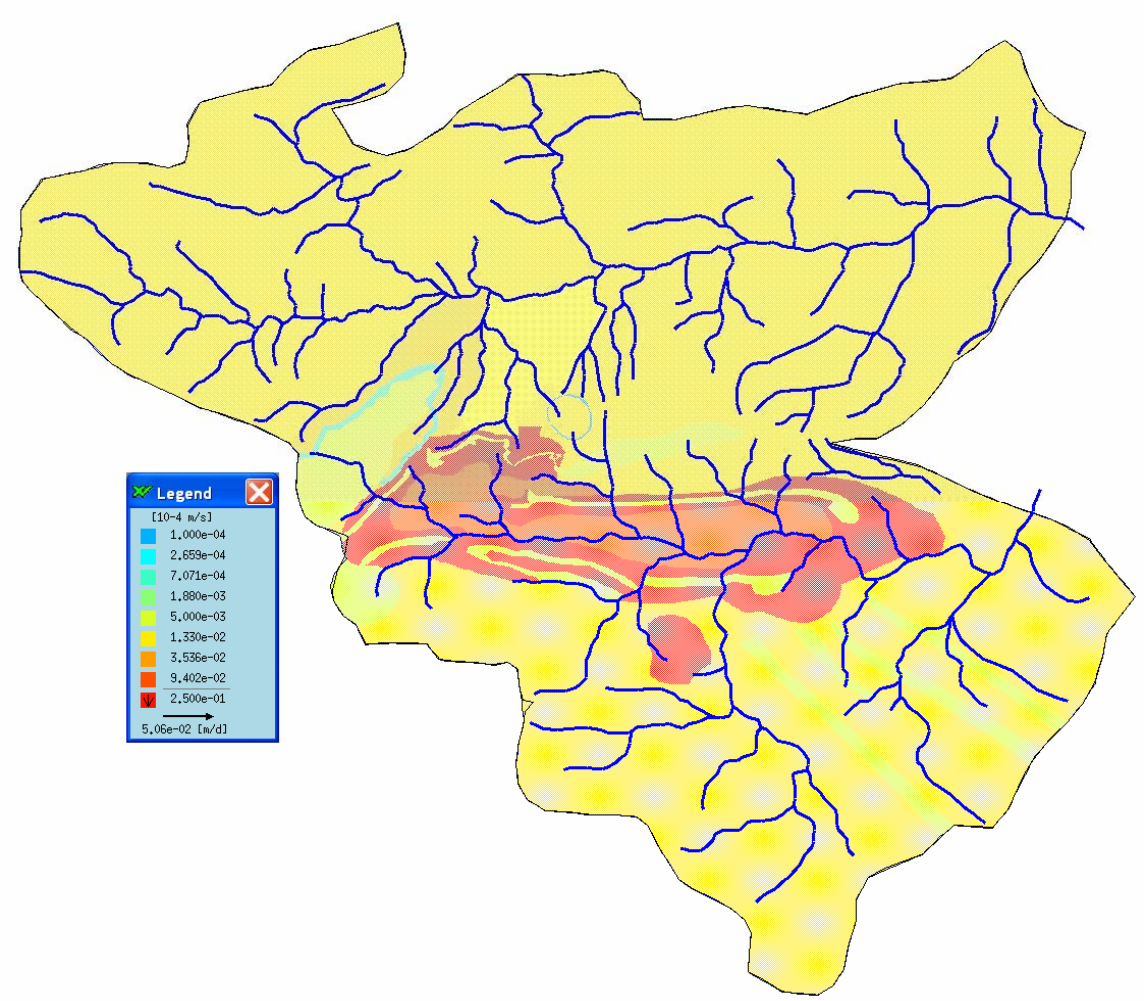
The components of the water balance were simulated in the numerical model using the FEFLOW software package. This included the "Inflow-Outflow from Surface" package to simulate natural groundwater recharge and the constant head boundary condition Type I to simulate outflow from the internal model boundaries and inflow into the open pit mine.

6.8 CALIBRATION APPROACH

Calibration is the process of finding a set of parameters, boundary conditions and stresses that best reproduce the observed water levels and/or fluxes (Anderson and Woesner 1992). A standard trial-and-error approach to calibrate the model was used. Theoretically, hydraulic conductivity, hydraulic stresses (such as recharge rates from precipitation and stockpile infiltration) and the hydraulic boundary conditions can be modified until the best possible match is made to the observed water level conditions. The groundwater level data shown on Figure 13 were used for steady state model calibration purposes.

After the set of parameters that resulted in the best match to the observed groundwater levels was determined, a sensitivity analyses was performed. A sensitivity analyses is important to quantify the uncertainty in the calibrated model caused by uncertainty in estimates of the model input parameters. As described later in Section 7, the model results were found to be sensitive to the values of particular model parameters. This uncertainty, therefore, must be taken into account when evaluating the model predictions. Hydraulic conductivity and hydraulic stresses (groundwater recharge) were tested and the model response was noted. As part of this process, better combinations of parameters were found to result in a better model calibration and the sensitivity analysis was repeated on the new calibration.

Figure 17 **Surface Expression of the Assigned Hydrostratigraphic Units (Initial Hydraulic Conductivity Distribution)**



7 MODEL CONSTRUCTION, CALIBRATION AND SENSITIVITY ANALYSES

7.1 MODEL AREA AND FINITE ELEMENT MESH

The numerical model encompasses the area of the Kwatebala pit, the mine facilities and extends to cover a large region around the mine over a total area of 905 square kilometers. The modeling area includes contiguous portions of the Mofia, Dipeta and Tshilongo river catchments.

7.1.1 Construction of the Finite Element Grid

A finite element network (grid) was designed to provide a high resolution of the numerical solution, while at the same time, accommodating the large model area.

The finite element grid was compiled using the FEFLOW pre-processing software, which facilitated the construction of 6-noded triangular prism elements over the area of investigation as shown in Figure 18. The triangular grid consists of 186,189 elements and 125,652 nodes. The positions of the hydrostratigraphic units are incorporated in the modeling grid as well as the various surface catchments. Smaller cell sizes were specified in the areas of the proposed tailing storage facility, waste rock facility and stock piles and mine pit where dewatering occurs and where a more accurate solution of the groundwater flows is required. Slightly larger cell sizes were specified in other areas. The model consists of three layers with constant thicknesses of respectively 50, 100 and 300 meters for a total model thickness of 450 meters. The elevation of the top slice was set equal to the topographic elevation.

7.2 MODEL BOUNDARIES

7.2.1 Model Perimeter and Internal Boundaries

No-flow boundaries were used to represent the hydrologic boundaries of watersheds for the entire model perimeter. As described earlier a watershed boundary approximately represents a natural groundwater divide across which no groundwater flows and is therefore appropriate to represent as a no-flow boundary. Thus, all groundwater within the study area was assumed to originate as either spatially distributed areal recharge within the model domain or as focused recharge beneath the unlined facilities. It is thought that most of the groundwater recharge occurring within the study area discharges internally to the surface drainage systems via springs and discharge to the base of river drainage systems (baseflow). Constant head boundary (drain) conditions were therefore specified along some of the major surface drainages which are known to receive baseflow from groundwater.

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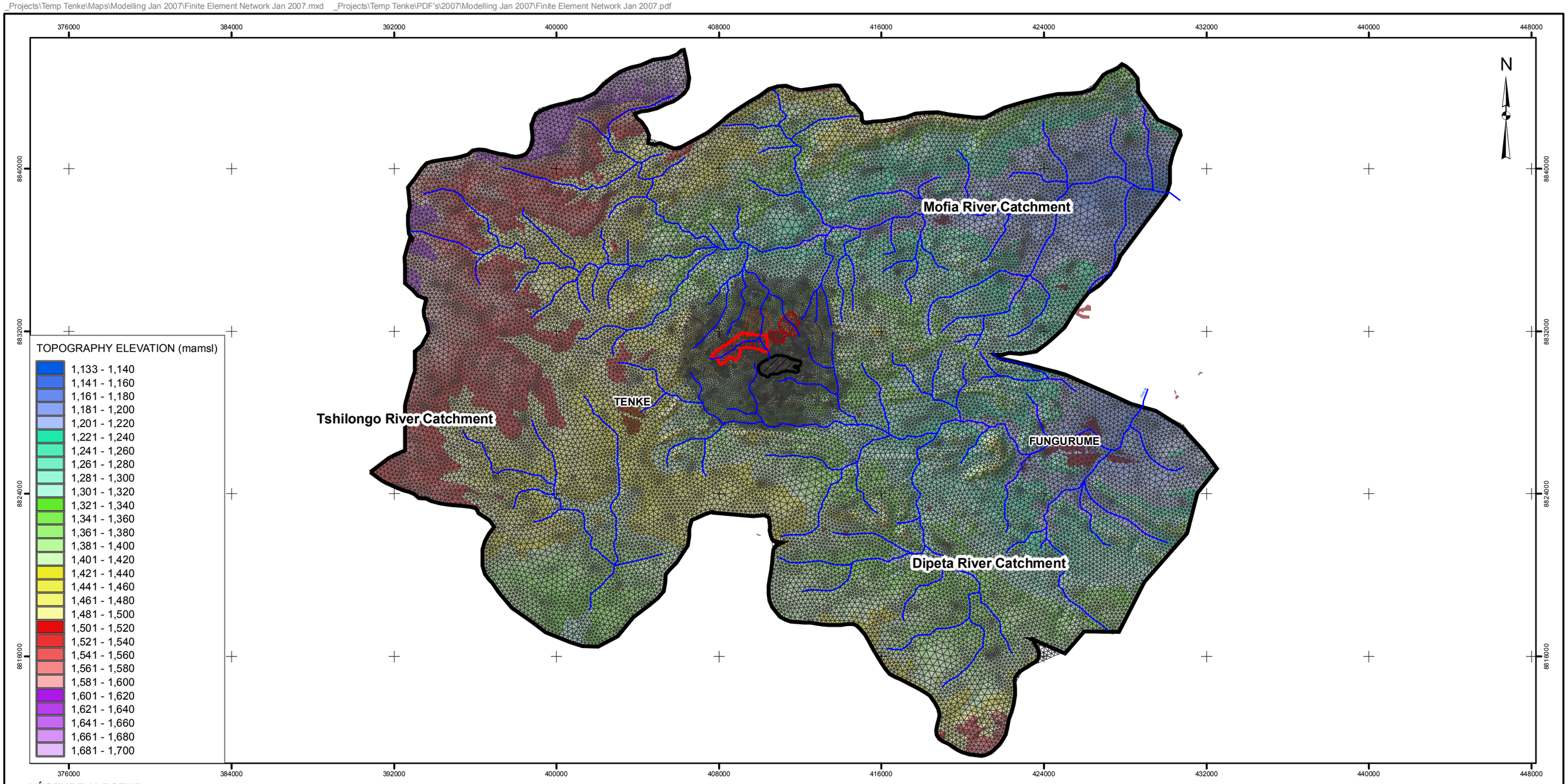

LÉGENDE / LEGEND

- FINITE ELEMENT NETWORK
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

FINITE ELEMENT NETWORK

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN
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GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

FIGURE: 18

7.2.2 Topography

The pre-mining topography was used to specify the land surface topography in the model. FEFLOW's constant head boundary condition was used to define the pit seepage in Slice 3 (bottom of Layer 2) in the model. If the model-calculated groundwater level was above the seepage face elevation, groundwater would exit the model, representing groundwater discharge to the pit.

7.3 MODEL PROPERTIES

7.3.1 Hydraulic Conductivity and Transmissivity

The major hydrogeological units in the Tenke study area are described in previous sections of the report. The hydraulic conductivities of these units were assigned to the model based on the estimated hydraulic properties obtained from pumping tests conducted to date and first model calibration and sensitivity runs. Estimates of the hydraulic conductivity and transmissivity were obtained from the results of constant rate discharge tests. Table 5 shows the results of the pumping tests conducted up to the end of October 2006.

7.3.2 Storativity

For the steady-state model, storativity is not required.

For transient conditions (see transient simulations) storativity values of one, three and six percent were specified. These values are typical for the range in storativity in fractured rocks within the study area.

7.3.3 Recharge

The steady state calibration simulations were conducted using recharge values of approximately 240 millimeters per year, which corresponds to 20 percent of the estimated mean annual precipitation of 1,200 millimeters. Subsequent analysis included:

- For the mining phase a similar recharge rate was assigned to the entire surface area except for the tailings storage facility (zero millimeters per year because it will be lined).
- The natural aquifer recharge rate of 240 millimeters per year was assigned across the stockpiles and waste rock facilities.

- For the post-closure situation the natural recharge to the exposed rock in the pit area was increased to 40 percent of MAP (i.e., 480 millimeters per year). This was implemented to represent the potential for increased runoff/recharge from the pit slopes and subsequent infiltration or discharge to the pit lake.

7.3.4 Evapotranspiration

Evapotranspiration was not specified in the model. It is assumed that the (effective) recharge specified in the model has already overcome the effect of evapotranspiration losses from the system.

7.4 INITIAL HEAD CONDITIONS

The initial head conditions specified in the model were interpolated from the measured groundwater levels (Figure 13) using the Kriging technique and extrapolated to the nodes in the model.

7.5 STEADY STATE SIMULATION (CALIBRATION)

7.5.1 Steady State Flow Equation

For steady state conditions the groundwater flow equation (1) reduces to the following equation:

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) \pm W = 0 \qquad (2)$$

According to the conceptual model for the system the calculated head distribution (hx, y, z) is dependent upon the recharge from rainfall, hydraulic conductivity and boundary conditions. For a given hydraulic conductivity value (or transmissivity value) and set of boundary conditions specified, the head distribution across the aquifer can be obtained for a specific recharge value. This simulated head distribution can then be compared to the measured head distribution and the effective recharge values can be altered until an acceptable correspondence between measured and simulated heads is obtained.

7.5.2 Steady State Model Calibration Approach

7.5.2.1 Overview

The typical model calibration approach involves establishing the model framework (geology), hydraulic properties and boundary conditions and then comparing the model-predicted groundwater levels to the observed groundwater levels to develop a calibrated model, often described as the "expected conditions". In the case of this project, it was found that a good model calibration could be achieved assuming two slightly different, but both reasonable (based on current knowledge) geological frameworks. While these two geological interpretations both produced a similarly well-calibrated model, there was a difference in the magnitude and distribution of impacts (changes in groundwater levels, baseflow, groundwater flow paths, etc) predicted by the model. Hence, rather than assign one geological condition as the "expected conditions", it was considered appropriate to carry both geological conditions forward in the modeling and present the modeled impacts as a range rather than as a "single point estimate". Presenting a range of impacts and developing mitigation plans based on the range will ensure that the potential impacts are identified and that the mitigation measures are appropriate. Details of this approach are described below.

7.5.2.2 Geological Scenarios

Based on evaluation of the geological and hydrogeological data from the mine and surrounding area, two geological scenarios were developed in order to span the likely spread of hydrogeological conditions at Tenke and thus provide an assessment of the potential range of groundwater impacts for the ESIA. The two geological scenarios are:

- **Scenario 1** - Used the mapped surface/near-surface geology to delineate the extent and properties of the hydrogeological units.
- **Scenario 2** – Used the mapped surface/near-surface geology, but added additional hydrogeological boundaries, based on interpretations of the subsurface geology, where it was felt that these subsurface strata could substantially affect water flow within the three layers of the model.

Geological mapping and subsurface investigation suggests that the higher elevation ground at Kwatebala is underlain by lower Roan (RAT) materials (see Figure 9). These materials are generally of lower permeability than the overlying dolomitic aquifer. As a result, for Scenario 2, lower hydraulic conductivity values were assigned to the zones of west-to-east running topographical highs

based on the hypotheses that these higher elevation areas are underlain by lower permeability RAT/RGS units.

Steady state calibration of both geological scenarios was accomplished by varying the hydraulic conductivity values and keeping the recharge rate constant at 240 millimeters per year, until a reasonable match between the measured groundwater elevations and the simulated groundwater elevations was obtained. A constant recharge was used because localized recharge variations (based on slope or soil type) cannot be determined with the limited data available at this time. For the purpose of this modeling study, a constant recharge rate is considered reasonable and likely to result in similar regional predictions compared to spatially distributed recharge. The two geological scenarios were calibrated using groundwater levels measured during the 2006 drilling and testing program. Figure 11 shows the locations of target boreholes used for calibration purposes.

7.5.3 Steady State Calibration Results

Scenario 1

Figure 19 shows the simulated steady state groundwater elevations and groundwater flow directions for Scenario 1. There are insufficient boreholes with groundwater level data to create an observed water table map for the entire model area. Therefore, the model output has been evaluated in a qualitative manner by observing the shape of the water table contours near known hydraulic boundaries, divides and drainages. The calibrated model water table is similar to what would be expected at the location of internal watersheds divides and major drainages and is reasonable in the vicinity of the proposed pit where most of the target boreholes are located. As shown on Figure 19, the water table closely conforms to local topographic features.

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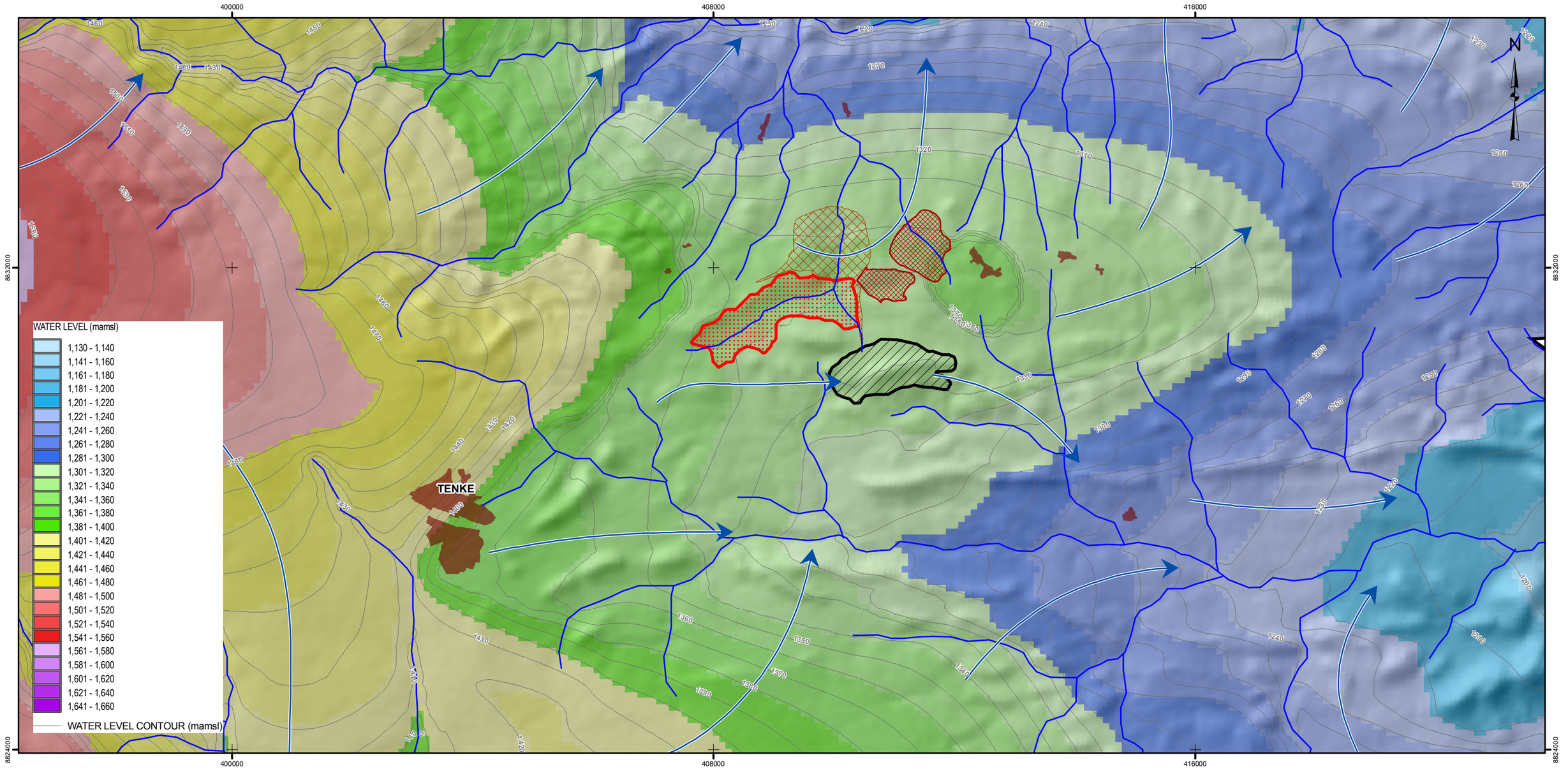

LÉGENDE / LEGEND

- GROUNDWATER FLOW DIRECTION
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

1 0 1 2 3 4 5

ÉCHELLE 1:65,000 KILOMÈTRES
SCALE 1:65,000 KILOMETRES

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

SIMULATED STEADY STATE GROUNDWATER LEVELS AND FLOW DIRECTIONS SCENARIO 1 CALIBRATION

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
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APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 19

American Society for Testing and Materials (ASTM) guidelines, as well as widely accepted methods presented in Anderson and Woessner (1992) and Spitz and Moreno (1996) were followed for calibration of the model. The difference between the simulated and the observed hydraulic head (residual) was calculated for each target (Table 6). The error in the calibration was expressed by three common methods: the mean error (ME), the mean absolute error (MAE) and the root mean squared (RMS) error (Anderson and Woessner 1992). The ME is the mean difference between measured (WLm) and simulated (WLs) water levels:

$$ME = 1/n \Sigma(WLm- WLs)i$$

For i=1 to n, the number of calibration targets.

A small ME is not necessarily an indication of a good calibration, because negative and positive residuals, even if large, can cancel each other out, resulting in a small ME. The MAE addresses this as the mean of the absolute value of the differences in measured and simulated water levels:

$$MAE = 1/n \Sigma |(WLm- WLs)i|$$

The RMS error is the average of the squared differences in measured and simulated water levels:

$$RMS = [1/n \Sigma(WLm- WLs)i2]0.5$$

In keeping with standard practice, the RMS error was evaluated as a ratio to the total water level change across the model domain. If the ratio is small, the errors are only a small part of the overall model response (Anderson and Woessner 1992).

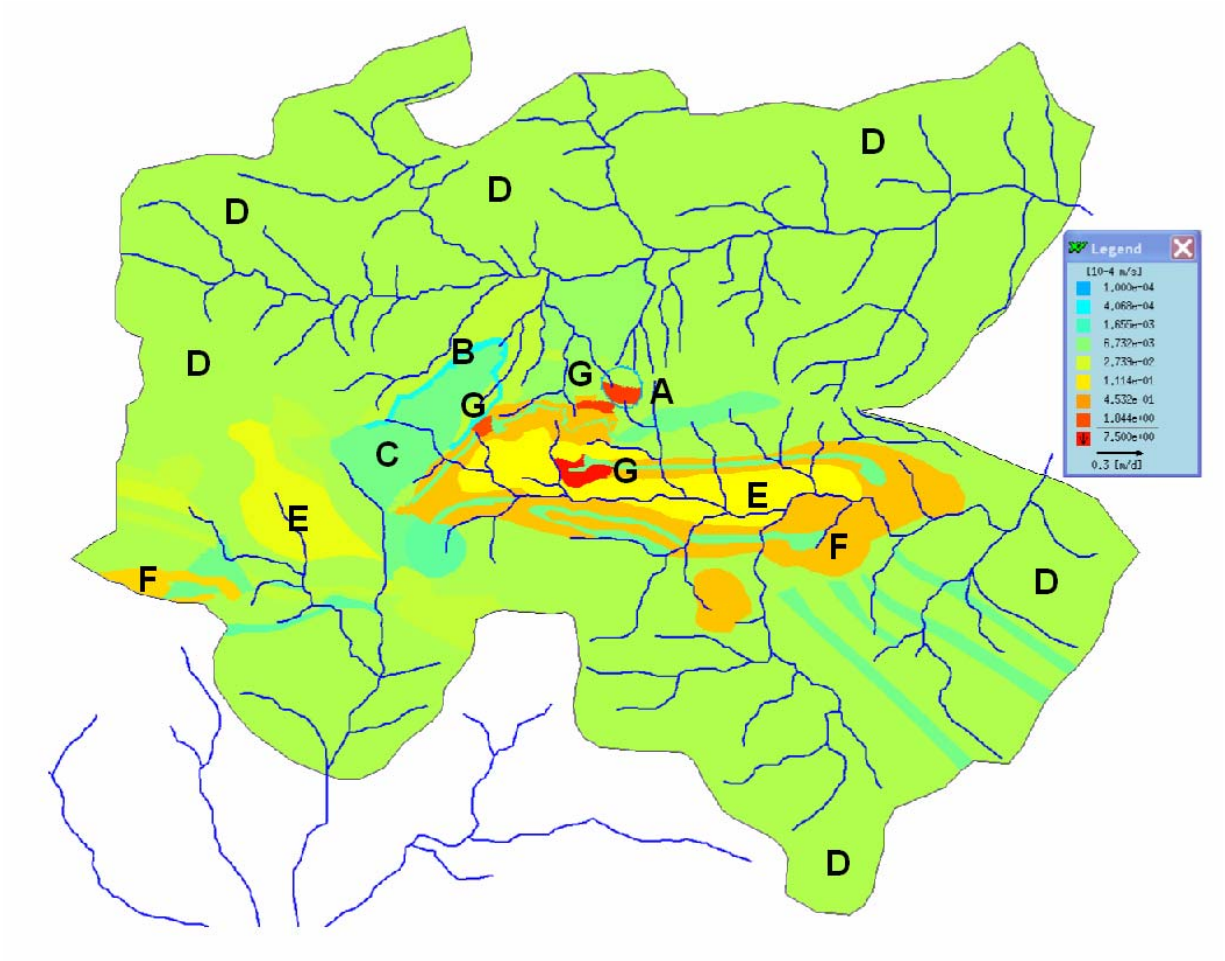
Estimates of the hydraulic conductivity for the calibrated model are summarized in Table 7 and depicted in Figure 20.

Table 6 Steady State Calibration Measures for Scenario 1

Borehole	Observed SWL (mamsl)	Scenario 1 Simulated Water Level (mamsl)	ME (m) (WLm - WLs)i	MAE (m) (WLm - WLs)i	RMS (m) (WLm - WLs)i^2
TFM1	1161.97	1179.90	-17.93	17.93	321.32
TFM3	1180.79	1183.88	-3.09	3.09	9.54
TFWB12	1304.27	1303.56	0.71	0.71	0.50
TFWB10	1290.67	1316.20	-25.53	25.53	651.93
TFWB09	1313.97	1314.47	-0.50	0.50	0.25
TFWB08	1320.43	1320.41	0.02	0.02	0.00
TFM4	1353.41	1328.46	24.95	24.95	622.60
TFEB10	1348.76	1352.13	-3.37	3.37	11.35
TFEB5	1355.54	1340.63	14.91	14.91	222.16
TFWB01A	1344.88	1332.81	12.07	12.07	145.64
THG3	1358.15	1349.69	8.46	8.46	71.53
TFM5	1358.64	1346.15	12.49	12.49	156.05
TFWB06A	1371.80	1370.06	1.74	1.74	3.04
TFEB06	1384.66	1388.59	-3.93	3.93	15.44
TFM6	1347.72	1342.41	5.31	5.31	28.19
TFWB05	1384.19	1388.75	-4.56	4.56	20.79
TFEB07	1340.06	1348.03	-7.97	7.97	63.60
TFWB04	1335.75	1334.26	1.49	1.49	2.21
TFWB03A	1350.89	1343.46	7.43	7.43	55.23
TFWB2	1352.08	1333.16	18.92	18.92	357.98
TFEB08	1328.05	1341.66	-13.61	13.61	185.27
TFEB12	1358.41	1338.41	20.00	20.00	399.85
			Σ 47.99	Σ 208.98	Σ 3344.48
			1/n=2.18	1/n=9.50	1/n=152.02
					SQRT=12.33
					RMS% of water level range = 5.54

The ME, MAE and RMS error were calculated using all of the calibration targets and were 2.18, 9.5 and 12.33 meters, respectively. The RMS error was 5.54 percent of the range of water level change across the model domain (Table 6).

Figure 20 **Hydraulic Conductivity Distribution Steady State Calibration – Scenario 1**



The observed groundwater levels were plotted against the simulated water levels in a scatter plot (Figure 21). Deviations from the straight line indicating a perfect match between the observed and simulated values should be randomly distributed indicating that there is no bias toward over or under predicting the groundwater levels (Anderson and Woessner 1992). A correlation coefficient of 97.8 percent was obtained between the simulated and observed groundwater elevations. The plot of the modeling errors (Figure 22) indicates that this scenario is generally slightly under-predicting the groundwater levels.

Table 7 Hydraulic Parameters Obtained During Steady State Calibration

Zone	Hydraulic Conductivity (m/d)	Transmissivity Layer 1 (m^2/d)	Transmissivity Layer 2 (m^2/d)	Transmissivity Layer 3 (m^2/d)
A	0.0009	0.05	0.1	0.27
B	0.0086	0.43	0.86	2.58
C	0.0432	2.16	4.32	12.96
D	0.1296	6.48	12.96	38
E	0.1728	8.64	17.28	51.8
F	0.6480	32.40	64.8	194
G	2.16	108	216	648

(see Figure 17 for zones)

Scenario 2

Figure 23 shows the simulated steady state groundwater elevations and groundwater flow directions for Scenario 2. Table 8 shows the steady state calibration measures for Scenario 2. The ME, MAE and RMS error were calculated using all of the calibration targets and were 5.23 meters, 6.38 meters and 8.8 meters, respectively. The RMS error was 3.95 percent of the range of water level change across the model domain (Table 8).

Figures 24 and 25 respectively show the hydraulic conductivity distribution in the Kwatebala area for Scenario 1 and 2 steady state calibrations. The interpreted east to west striking low hydraulic conductivity zones north and south of the Kwatebala pit specified for Scenario 2 can be observed by comparing the two figures. The observed groundwater elevations were plotted against the simulated groundwater elevations in a scatter plot (Figure 26). A correlation coefficient of 99.1 percent was obtained between the simulated and observed groundwater elevations. Figure 27 shows the plot of the modeling errors which indicates that the model is generally not under or over-predicting groundwater elevations.

Figure 21 **Plot of Simulated Versus Observed Groundwater Levels - Scenario 1**

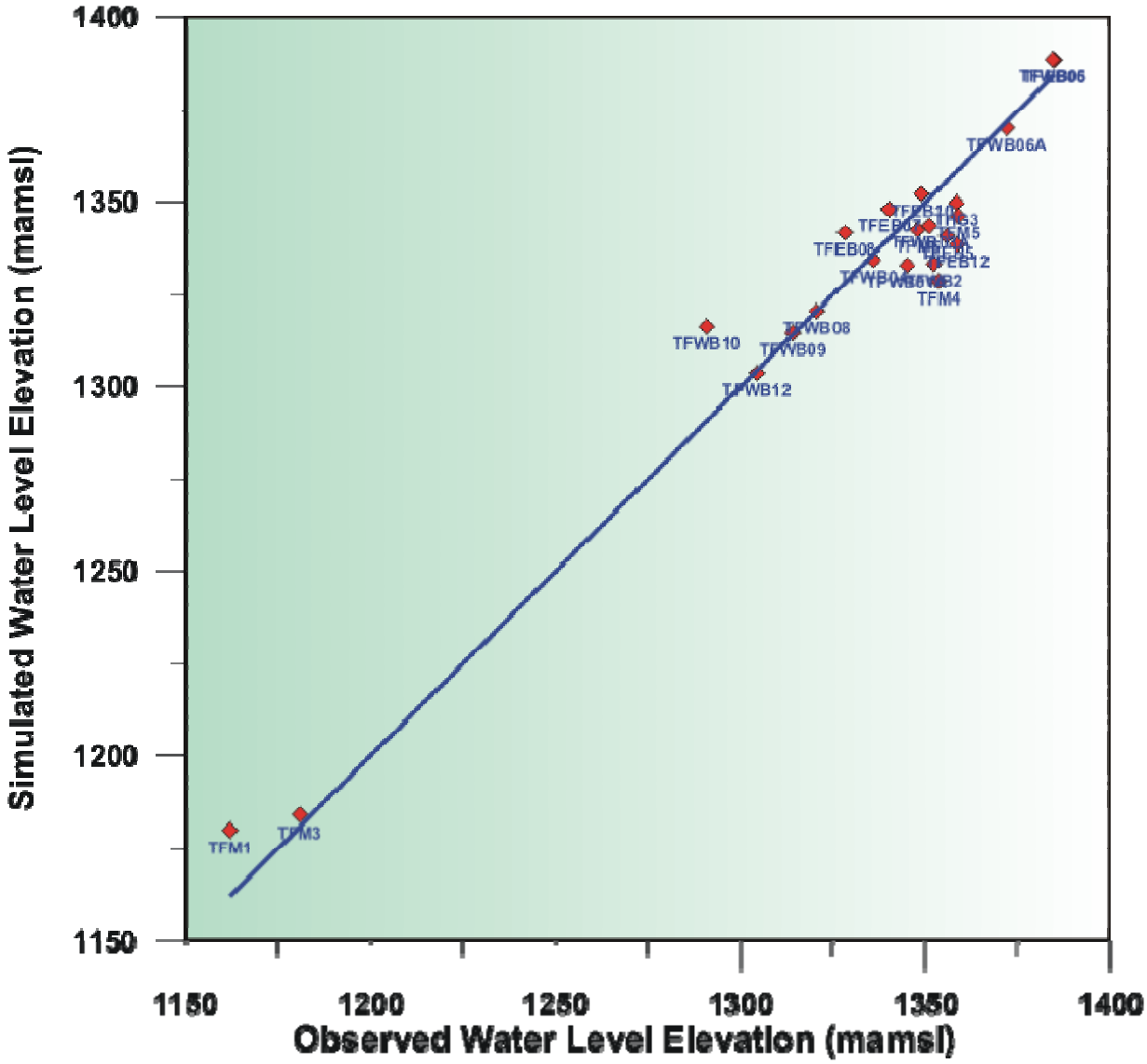
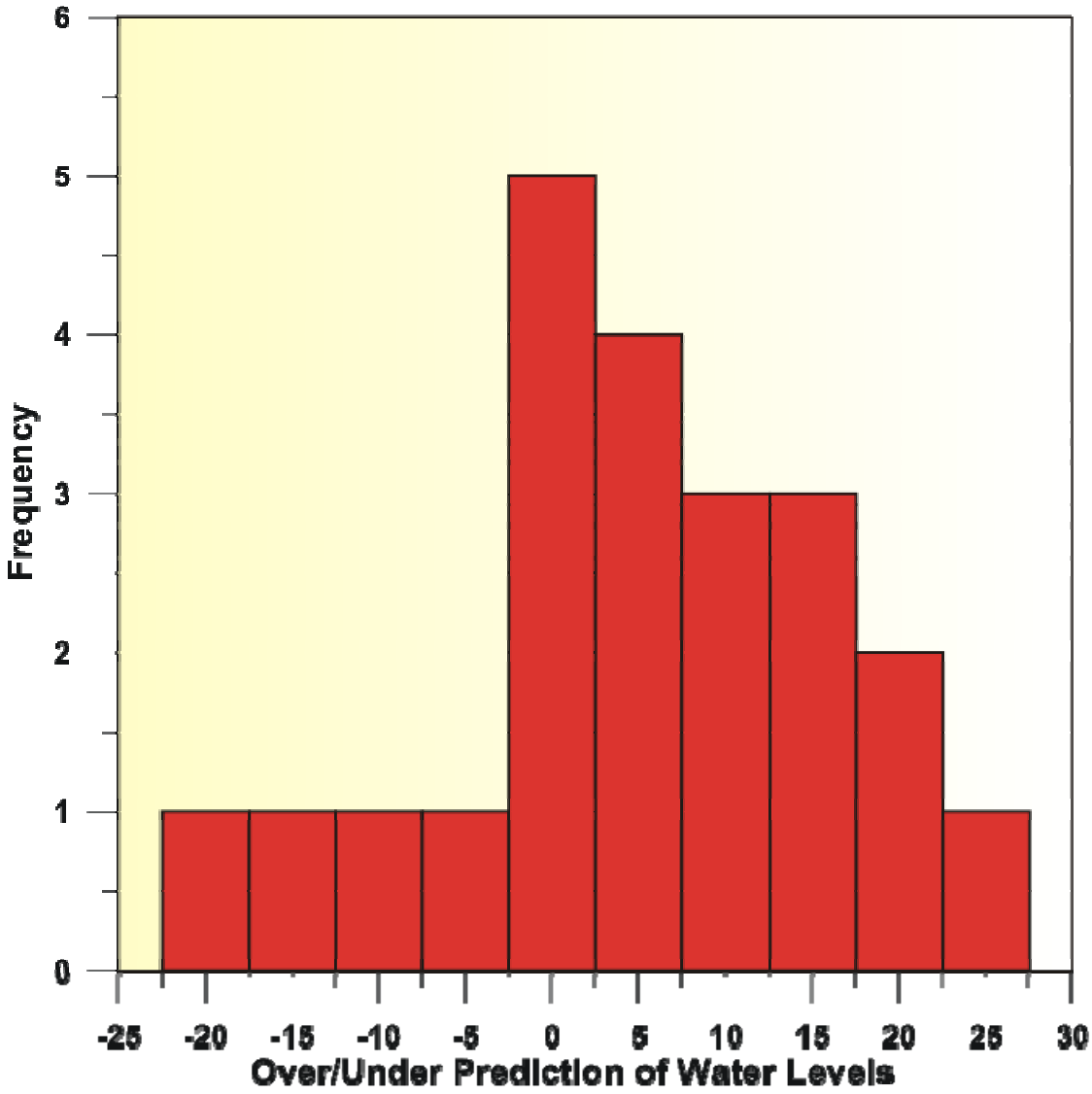


Figure 22 **Frequency Distribution of Modeling Errors – Scenario 1 Calibration**



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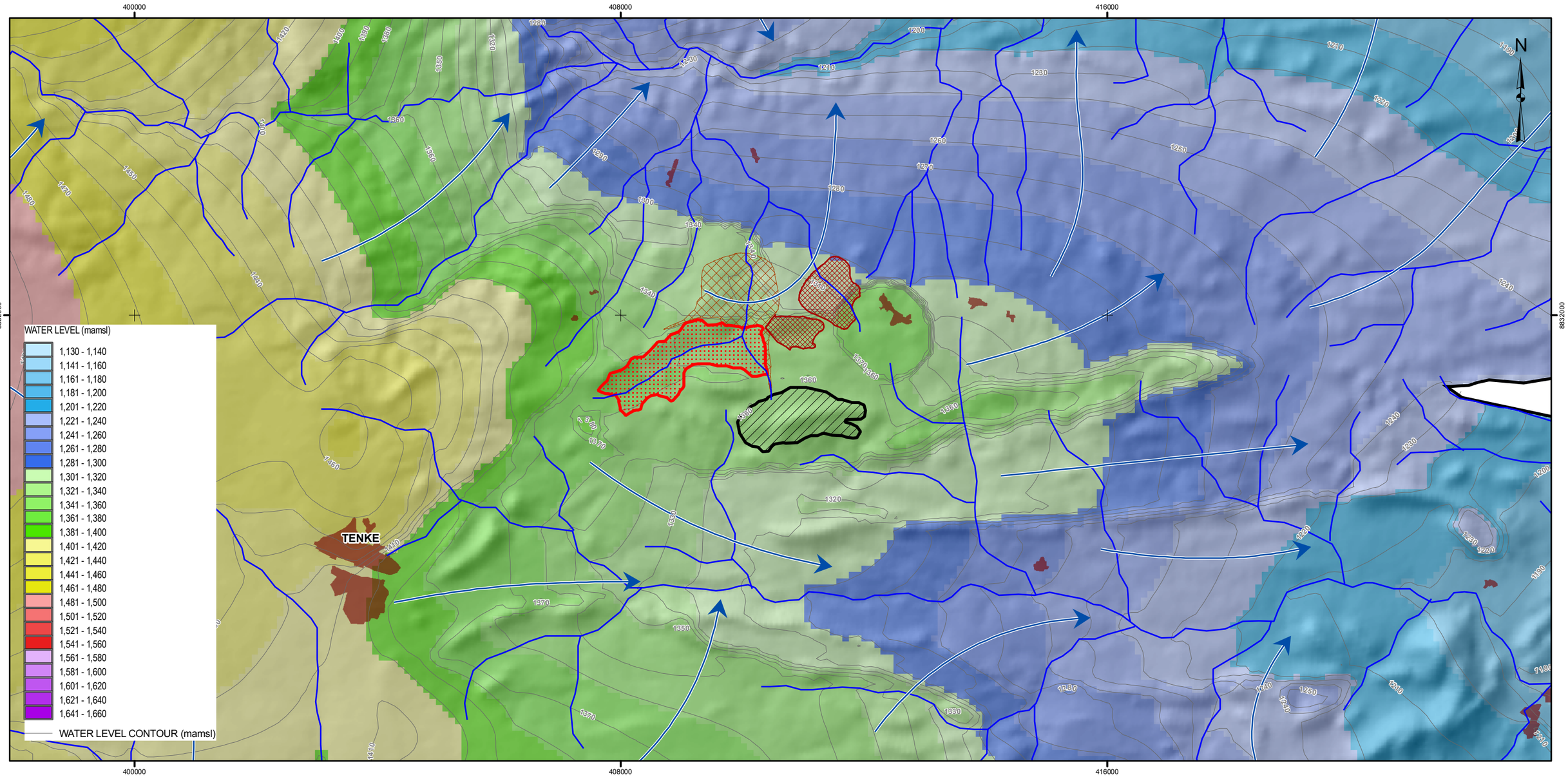

LÉGENDE / LEGEND

- GROUNDWATER FLOW DIRECTION
- FOSSE / MINE PIT
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RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

1 0 1 2 3 4 5

ÉCHELLE 1:65,000 KILOMÈTRES
SCALE 1:65,000 KILOMETRES

PROJET / PROJECT

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TENKE FUNGURUME MINING SARL

TITRE / TITLE

SIMULATED STEADY STATE GROUNDWATER LEVELS AND FLOW DIRECTIONS SCENARIO 2 CALIBRATION

Golder Associates
Johannesburg, South Africa

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GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
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FIGURE: 23

Figure 24 Hydraulic Conductivity Distribution for Scenario 1 Calibration

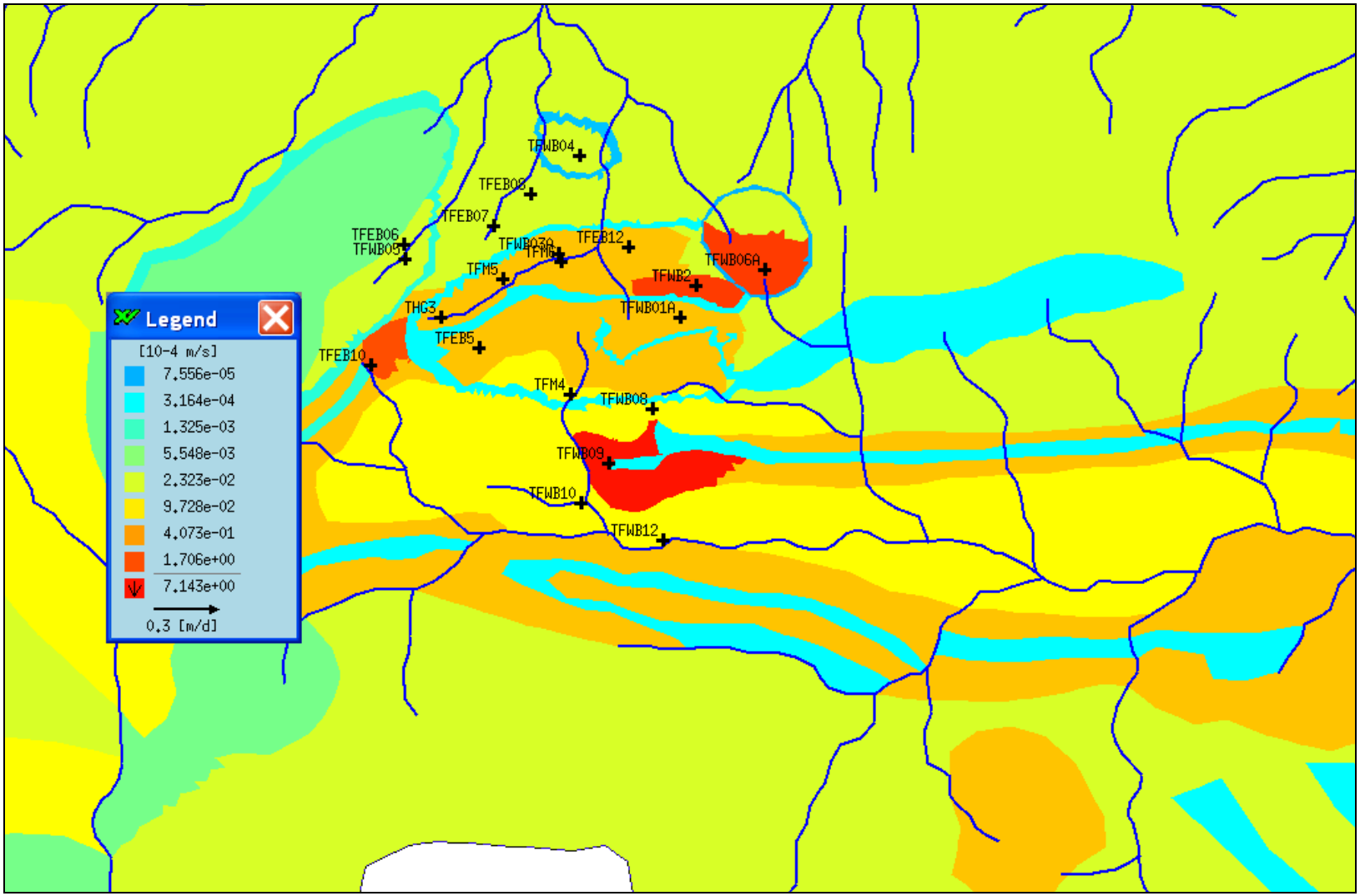


Figure 25 Hydraulic Conductivity Distribution for Scenario 2 Calibration

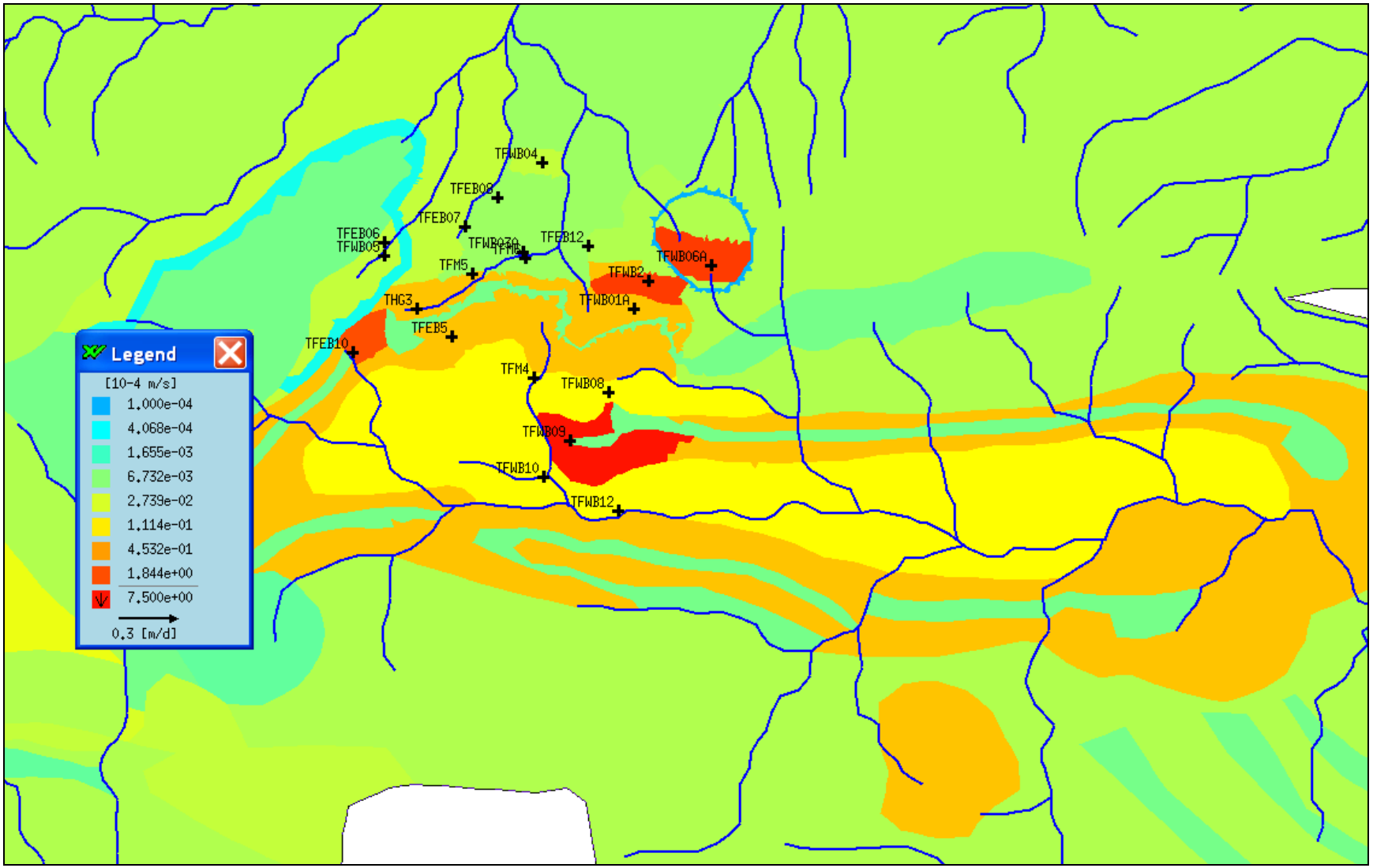


Figure 26 **Plot of Simulated vs. Observed Groundwater Levels - Scenario 2 Calibration**

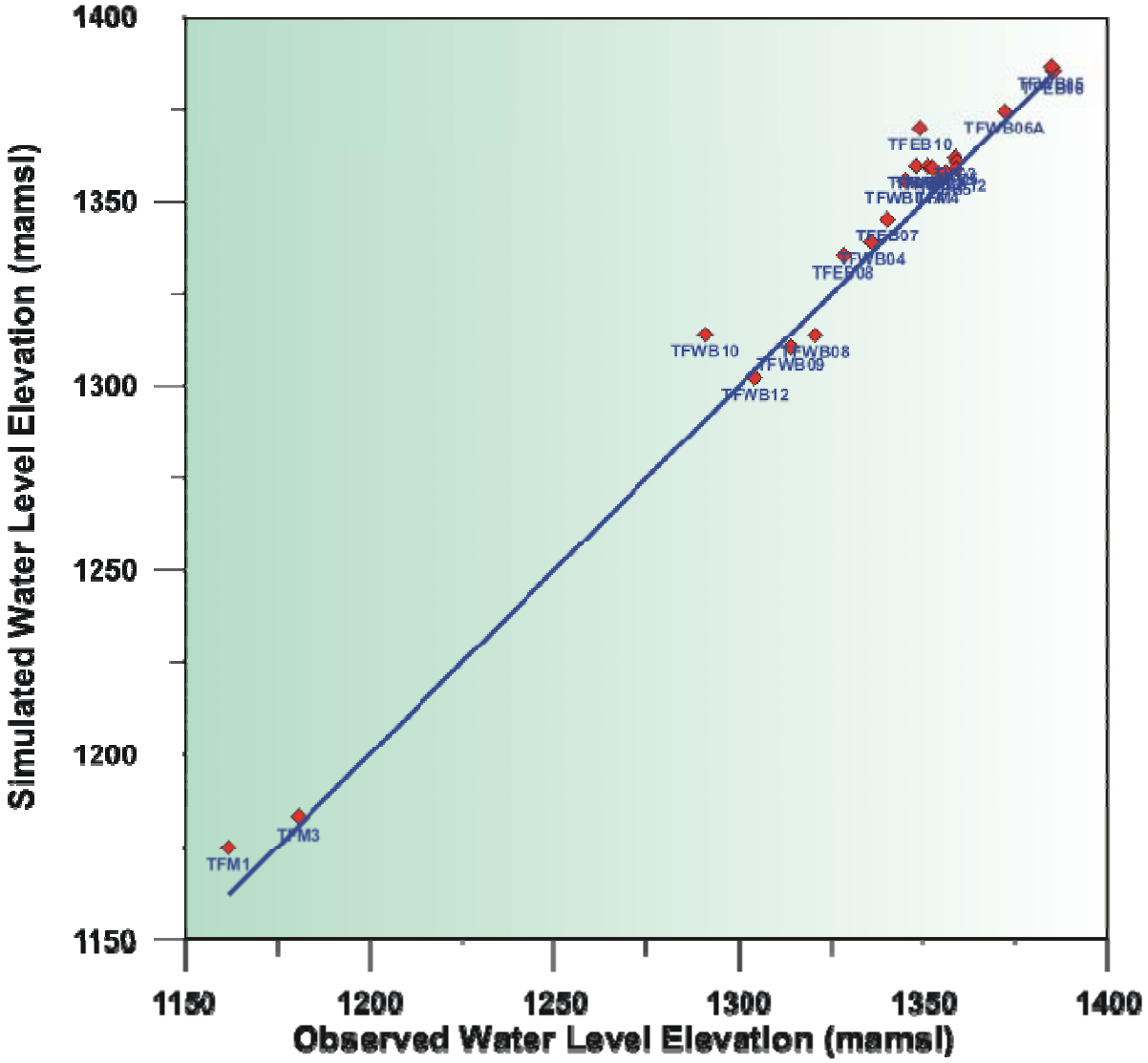


Figure 27 **Frequency Distribution of Modeling Errors - Scenario 2 Calibration**

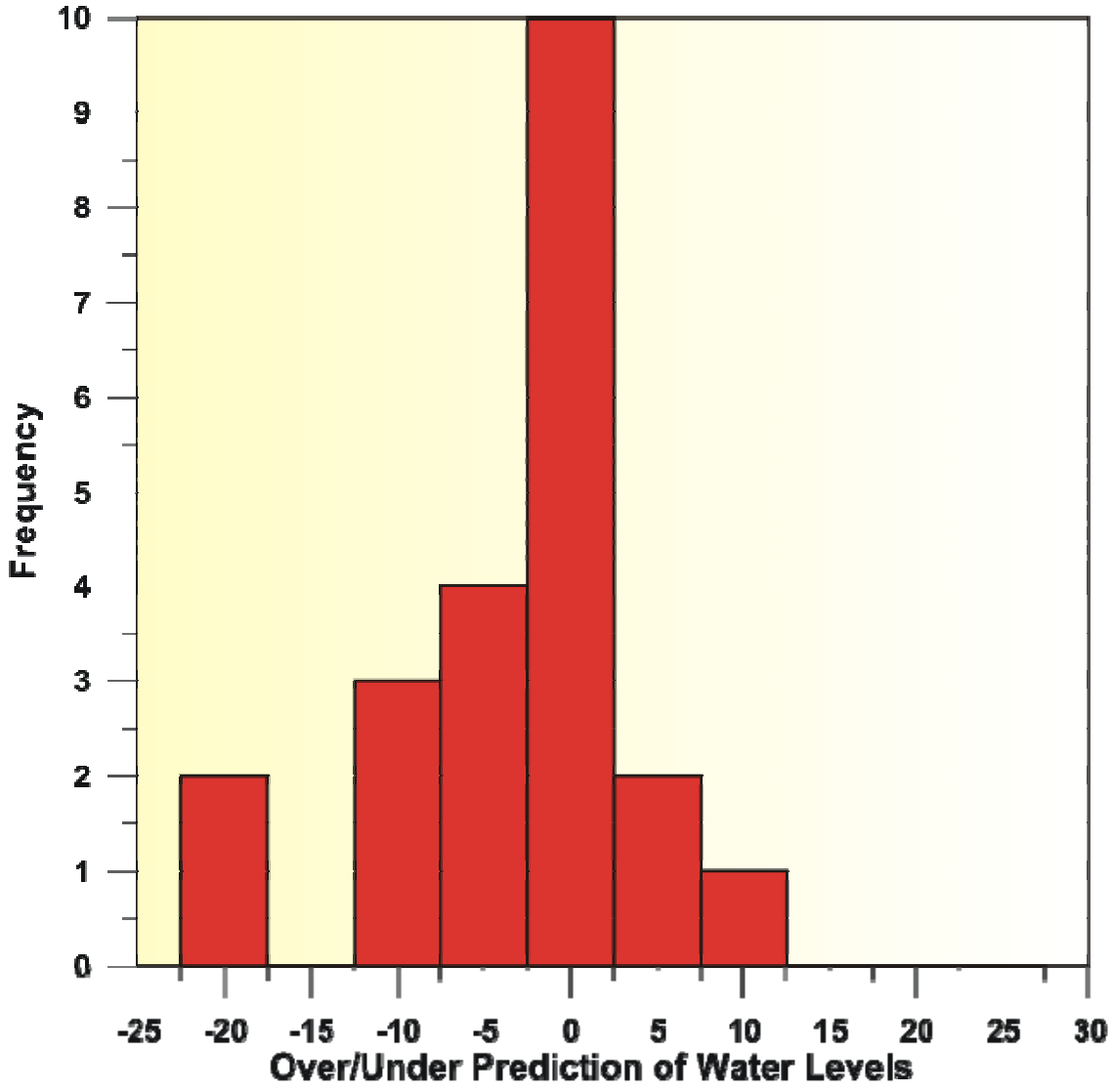


Table 8 Steady State Calibration Measures for Scenario 2

Borehole	Observed SWL (mamsl)	Scenario 2 Simulated Water Level (mamsl)	ME (m) (WLm - WLs)i	MAE (m) |(WLm - WLs)i|	RMS (m) (WLm - WLs)i^2
TFM1	1161.97	1174.82	-12.85	12.85	165.19
TFM3	1180.79	1183.20	-2.41	2.41	5.83
TFWB12	1304.27	1302.08	2.19	2.19	4.80
TFWB10	1290.67	1313.79	-23.12	23.12	534.58
TFWB09	1313.97	1310.26	3.71	3.71	13.79
TFWB08	1320.43	1313.58	6.85	6.85	46.86
TFM4	1353.41	1355.40	-1.99	1.99	3.96
TFEB10	1348.76	1369.82	-21.06	21.06	443.41
TFEB5	1355.54	1357.74	-2.20	2.20	4.86
TFWB01A	1344.88	1355.48	-10.60	10.60	112.41
THG3	1358.15	1361.75	-3.60	3.60	12.94
TFM5	1358.64	1360.53	-1.89	1.89	3.59
TFWB06A	1371.80	1374.40	-2.60	2.60	6.76
TFEB06	1384.66	1385.27	-0.61	0.61	0.37
TFM6	1347.72	1359.42	-11.70	11.70	136.87
TFWB05	1384.19	1386.42	-2.23	2.23	4.99
TFEB07	1340.06	1345.12	-5.06	5.06	25.61
TFWB04	1335.75	1338.72	-2.97	2.97	8.79
TFWB03A	1350.89	1359.39	-8.50	8.50	72.25
TFWB2	1352.08	1358.96	-6.88	6.88	47.37
TFEB08	1328.05	1335.14	-7.09	7.09	50.22
TFEB12	1358.41	1358.74	-0.33	0.33	0.11
			Σ -114.96	Σ 140.46	Σ 1705.58
			1/n=-5.23	1/n=6.38	1/n=77.53
					SQRT=8.80
					RMS% of water level range = 3.95

7.6 TRANSIENT CALIBRATION

A preliminary transient calibration was undertaken based on the water levels measured in boreholes during the constant rate pumping tests. Both steady state scenarios were used in the transient calibration. The model was used to simulate the measured water levels during the pumping tests assuming a storativity of three percent under the two scenarios. The transient model simulated the

recorded water level changes with time indicating that the two scenarios are representative of the hydraulic conditions in the vicinity of the pumping wells.

7.7 CONCLUSIONS OF MODEL CALIBRATION

The following is concluded from the groundwater flow calibrations.

Sensitivity to regional scale hydraulic conductivity and effective groundwater recharge. The steady state model could not be calibrated using the measured high transmissivity values (4,000 to 5,000 square meters per day) determined from the pumping tests (Table 5) and a recharge of 240 millimeters per year. Calibration could only be achieved with a transmissivity in the range of 70 to 800 square meters per day. Recharge greater than 240 millimeters per year was considered unreasonable given the water balance and streamflow simulations. It is therefore postulated that the high transmissivity zones are associated with limited extent local-scale features that are likely bounded by low-permeability zones – the concept of compartmentalization from the geological structure.

Sensitivity to local scale hydraulic conductivity. In order to explain high groundwater level elevations in localized areas, zones of low hydraulic conductivity are required to hydraulically isolate zones of much higher hydraulic conductivity in which the water levels are measured, (e.g., borehole TFWB06A). This effectively compartmentalizes certain areas and substantiates the effects described with regards to the geology, hydrogeological units and the conceptual aquifer model.

The hydraulic conductivity zoning used in Scenarios 1 and 2 corresponds with the nature and distribution of the geological units and the geological structures which control the hydrogeology of the study area. The zoning mimics the primary geological feature in the regional study area, namely the Dipeta syncline. The hydraulic conductivity distribution corresponds with the geological sequence consisting of dolomite, sandstone and shale that range from relatively high to low permeability. The large-scale, effective hydraulic conductivity values identified in the model calibration compare well with the hydraulic conductivity (transmissivity) data from the pumping tests.

The background recharge of 240 millimeters per year used in the model is consistent with previous estimates presented (SRK 1998).

The steady state water balance for the modeled area indicates groundwater outflow into the Dipeta/Mofia drainages of 514,000 cubic meters per day

(5,949 liters per second). This compares well with the total ACRU model-simulated surface water flows of 5,453 liters per second as simulated for the lower Dipeta and lower Mofia Rivers (see Table B.2.11-15 – Hydrology Baseline). The simulated surface water flow is primarily baseflow. The steady state water balance is made up as follows:

a. Model Inflows – Groundwater recharge = 603,772 cubic meters per day.
b. Model Outflows – Dipeta catchment = 244,038 cubic meters per day.
c. Model Outflows – Mofia catchment = 269,970 cubic meters per day.
d. Model Outflows – Tshilongo sub-catchment = 89,764 cubic meters per day.

Overall, the model structure and parameters used in the calibrated model appear appropriate and reasonable for the planned use. The model-calculated hydraulic heads are consistent with the target heads and the overall shape of the water table is consistent with that expected and discussed in the conceptual model. The model shows groundwater recharge occurring and discharging within the surface drainages consistent with the conceptual model.

The model is most sensitive to the nature and distribution of low-permeability units and their effects on groundwater elevations and compartmentalization Because there is uncertainty in the distribution of these low-permeability units, two scenarios were developed that may bound the likely range of site conditions with respect to the location, continuity and properties of low-permeability units. The model's three layers assume the same vertical distribution of these units. This simplification may decrease the certainty that the model has fully evaluated the potential for aquifer compartmentalization. However, the two scenarios both result in acceptable calibration in terms of groundwater elevations and overall directions and rates of groundwater flow.

There are several uncertainties with respect to the hydrogeological conditions and thus the numerical model. The primary uncertainty is related to the geological interpretation (the lateral and vertical extent of the hydrostratigraphic units and their hydraulic characteristics) and in particular uncertainty is greatest at distance from the Kwatebala pit. Close to the pit, there is good geological knowledge that has been used to develop the two model scenarios. Less detailed geologic information is available at a distance of several kilometers from the Kwatebala pit. Geological data and indirect interpretation of morphological features have been used to interpret the extent of low permeability units used in the current model.

8 GROUNDWATER FLOW MODEL RESULTS

8.1 INTRODUCTION

The numerical model was used to evaluate the future potential impacts of mining and mine closure on the groundwater regime in the area.

The main objectives of the groundwater flow modeling study are to:

- Simulate groundwater flow scenarios to evaluate:
  - The quantity of groundwater that will enter the Kwatebala pit as mining proceeds below the water table.
  - The impacts of pit dewatering on local and regional groundwater levels and effects on seeps/springs and surface water baseflow during mining and closure/post-closure.
  - The groundwater flow paths of seepage from the lined tailings storage facility and un-lined waste rock stockpiles and ore stockpiles.
  - The impacts of pumping wells for mine water supply.

As explained in Section 7.5.2, two geological scenarios were developed as part of the groundwater modeling. The two scenarios were developed because slightly different (but both possible) geological interpretations each resulted in appropriate model calibration but produced different results in terms of impacts to the groundwater system. Impacts are therefore presented as a range rather than a single-point estimate. The two scenarios developed during the steady state calibration exercise described in Section 7 of this report were used for the evaluation. The following sections summarize the model predictions as follows:

- Pit inflows – Section 8.2.
- Changes in groundwater levels from pit dewatering and seepage pathways from mine facilities – Section 8.3.
- Post-closure groundwater levels, pit lake development and seepage pathways – Section 8.4.
- Impacts on baseflow, springs and wells from dewatering and post-closure mine flooding – Section 8.5.
- Effects of mine water supply development – Section 8.6.

8.2 PIT INFLOWS

8.2.1 Mine Plan

The mine plan is presented in Section A4.1 and A4.3. Mining of the Kwatebala open pit will take place over a period of up to 19 years spanning 2008 to 2026. Mining is proposed to occur only at Kwatebala from 2008 to 2017, with additional intermittent periods of mining from 2023 to 2026. During some years, there will be little if any mining at Kwatebala while other deposits are mined.

Based on the current mine plan and groundwater elevations, it is estimated that mining from 2008 to about 2015 will be above the water table. During this time, there will not be any groundwater inflow to the pit. From this time onwards, the pit will be advanced below the water table and dewatering will be required to keep the pit dry.

The mine plan estimates that the Kwatebala pit will be mined to an ultimate elevation of about 1,270 m or about 75 to 80 m below the current water table (at its deepest point).

8.2.2 Incorporation of Open Pit Mine into Model

The open pit mine was incorporated into the groundwater flow model by specifying constant head nodes at the elevation of the pit floor that would be below the pre-mining water table. It was assumed that the open pit was above the water table for about the first eight years of mining. It was then assumed that dewatering was required until 2026.

The model assumed that dewatering occurred for 12 years from 2015 to 2026. It also assumed that the Kwatebala pit was mined to different depths across the ore body based on the mining plan. The pit was assumed to be deepest in the western quarter and shallower elsewhere. The maximum dewatering depth was assumed to be about 80 meters, with the northern, southern and eastern part of the pit mined to depths of 60, 40 and 40 meters below the water table respectively. It was also assumed that there was a period of no mining for four years (but that dewatering is continued) from 2018 to 2021.

Dewatering was assumed to operate in three stages: Stage 1 – rapid lowering of the water level from 2015 to 2018; Stage 2 – constant water level from 2018 to 2021; and Stage 3 – lowering of the water level from 2022 to 2026. An “island” of un-mined rock was assumed to be present in the center of the pit at the end of mining. Constraints were imposed on these constant head nodes such that water

could only be removed from the system. Modeling was conducted on a 30-day time step length.

For each scenario, inflow estimates were developed using a storativity value of three percent. This value is consistent with the value determined using the transient calibration process. Simulated inflows into the open pit are shown in Figure 28 for the two scenarios (Scenario 1 and Scenario 2).

Section 8.9 of this report includes an assessment of the combined effects of pit dewatering and pumping from production wells used to supply the mine/process plant water needs.

8.2.3 Model Results

8.2.3.1 Scenario 1 Inflows

Groundwater inflow to the open pit will gradually increase as the pit is mined below the water table. Figure 28 shows the increase in groundwater inflow to the pit over time for Scenario 1. Inflows will increase to about 650 liters per second after four years, then decrease over the next four years by about 100 liters per second, and increase again over the last four years of mining to about 650 liters per second.

8.2.3.2 Scenario 2 Inflows

Inflow to the pit will gradually increase as the pit is mined below the water table. Inflow rates at the end of mining are predicted to be about 200 liters per second. Inflow rates will be slightly less (125 liters per second) during the period of no mining.

8.2.3.3 Sensitivity of Inflow Estimates to Changes in the Dewatering Plan

In order to evaluate the sensitivity of the inflow estimates to the dewatering plan, additional simulations were performed using a slightly different dewatering schedule, herein referred to as the "modified dewatering plan". The modified dewatering plan assumed that dewatering (and mining) occurred for eight years. It was assumed that dewatering occurred at the perimeter of the open pit footprint and that all rock inside the footprint was mined.

Figure 28 Simulated Groundwater Inflow into the Kwatebala Pit During Mining

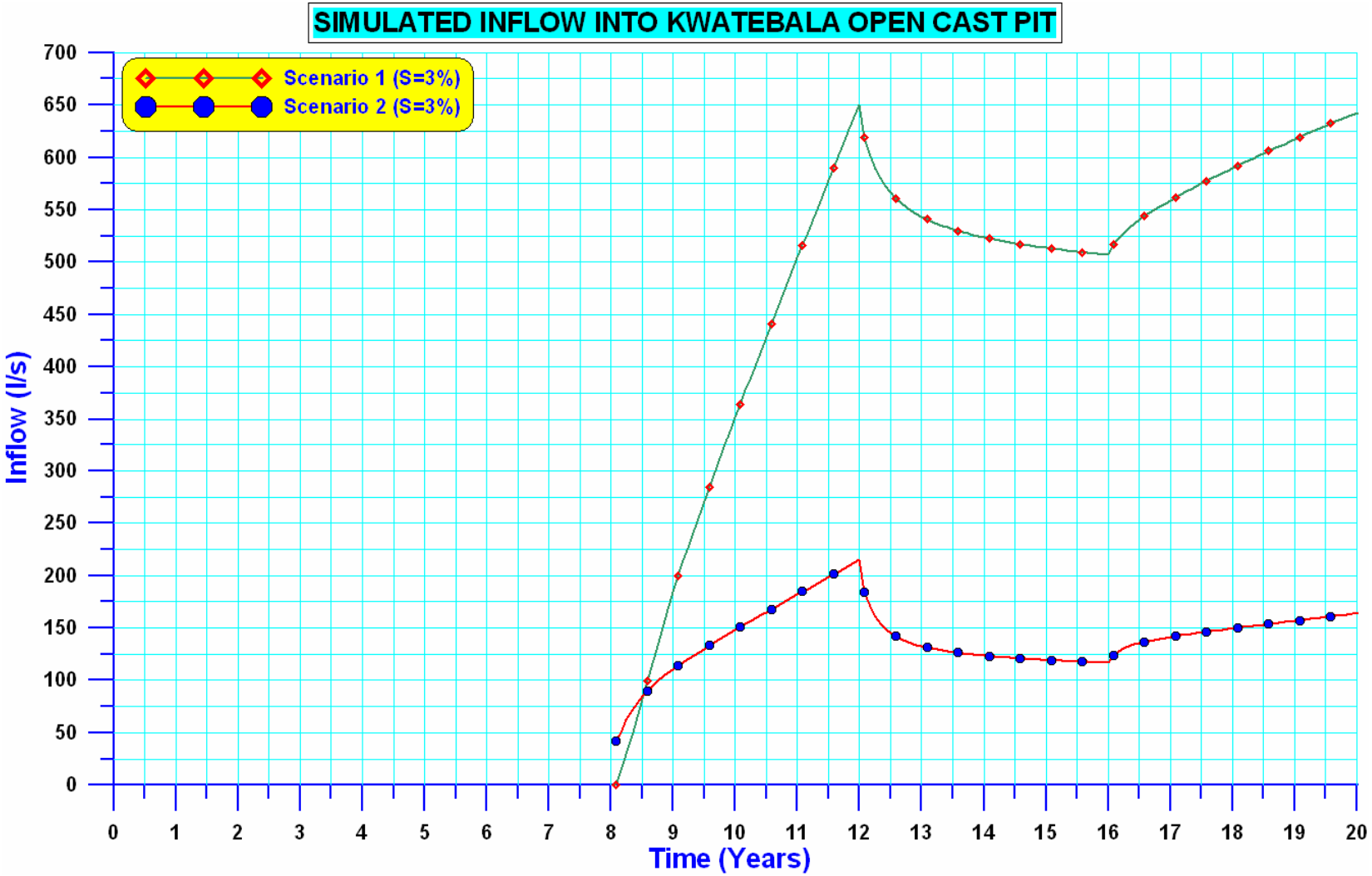
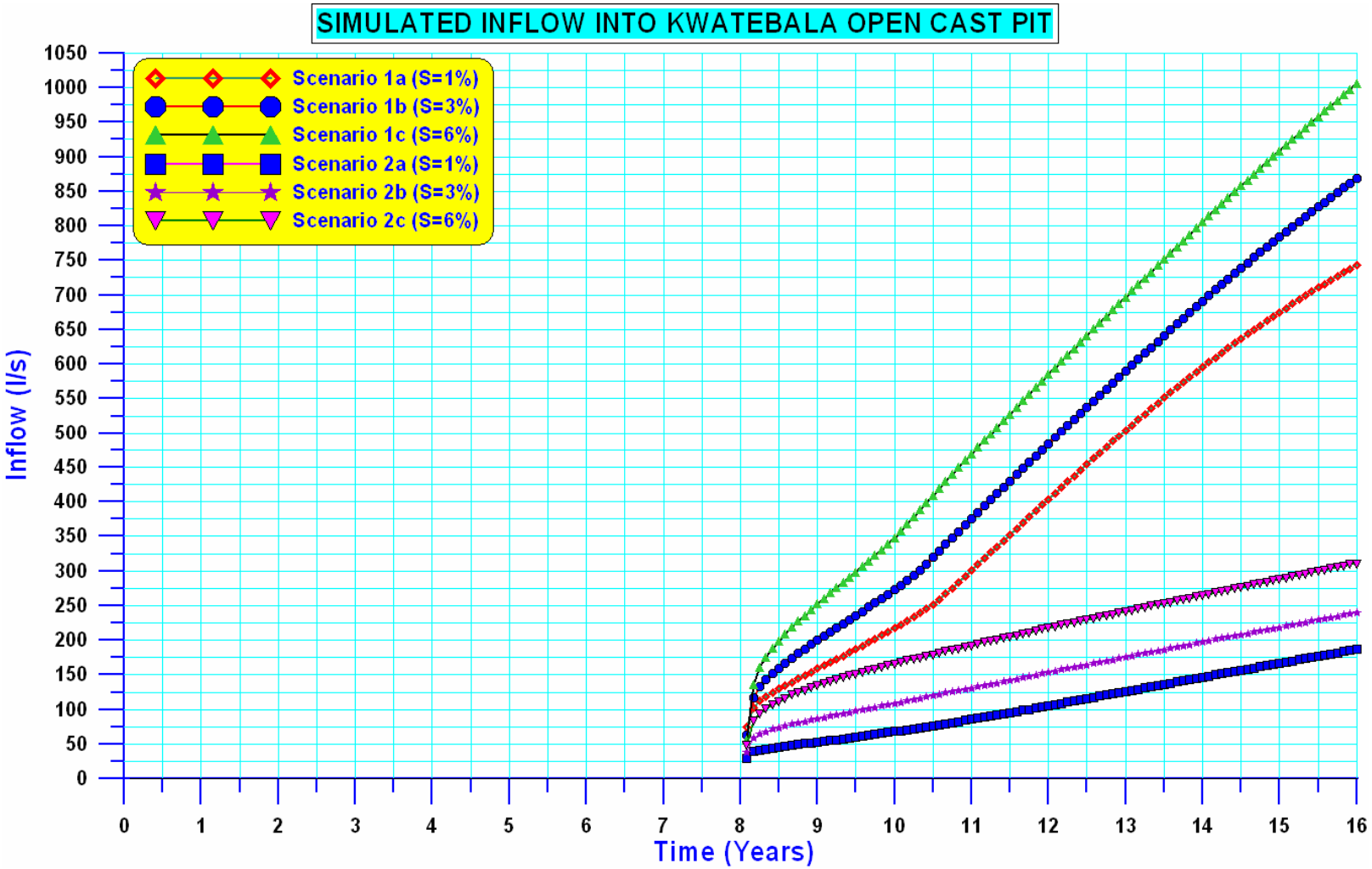


Figure 28a **Simulated Groundwater Inflow into the Kwatebala Pit During Mining - Sensitivity Analysis**



During the dewatering period, it was assumed that the pit advanced in depth by 10 meters each year. Therefore, the elevation of the constant head nodes was lowered by 10 meters each year from Year 9 to Year 16. Constraints were imposed on these constant head nodes such that water could only be removed from the system. Modeling was conducted on a 30-day time step length.

The two geologic scenarios were modeled assuming a storativity of three percent. The results are presented on Figure 28a. Inflow rates at the end of mining are predicted to be 750 liters per second (Scenario 1a), 860 liters per second (Scenario 1b) and 1,000 liters per second (Scenario 1c) for storativities of one percent, three percent and six percent, respectively. The inflow results are only marginally sensitive to the assumed storativity, as demonstrated by the 30 percent increase in predicted inflow with a six fold increase in storativity.

For Scenario 2, inflow rates at the end of mining are predicted to be about 200 liters per second (Scenario 2a), 240 liters per second (Scenario 2b) and 310 liters per second (Scenario 2c) for storativities of one, three and six percent, respectively.

Overall the estimated rates of dewatering in the modified dewatering plan are similar to those predicted under the original dewatering assumptions.

8.2.4 Discussion of Results

Inflow estimates using the Scenario 1 conceptual model are about three times greater than the Scenario 2 conceptual model. This is a result of the fewer low-permeability zones surrounding the pit compared to Scenario 2 which results in a larger capture zone for the pit. A larger capture zone enables a greater proportion of the spatial recharge to ultimately enter the pit as groundwater inflow.

The simulation assuming a modified dewatering schedule indicates that overall similar dewatering quantities can be expected. This suggests that modifications to the mine plan during operations (consistent with the modeling assumptions) will not have a significant effect on the dewatering quantities.

It is our opinion that the actual dewatering requirements are more likely to be toward the lower range predicted by Scenario 2 rather than Scenario 1. This is because if compartmentalization exists away from the pit (as it is present in the pit area), the effects will be to constrain the effects of dewatering to a smaller area and thus limit groundwater inflow to the pit. Monitoring data (groundwater levels) and pumping rates collected during the operation of the groundwater supply system will assist in the confirmation of the dewatering requirements.

8.2.5 Mine Water Management

The preliminary modeling indicates that groundwater inflows into the open pit could range between 200 and 650 liters per second. The simulated inflows can be classified as "high" and it is concluded that groundwater inflow may pose a risk to mining and that in-pit dewatering (mine sumps) is unlikely to be effective in managing the quantities of groundwater. A perimeter curtain of dewatering wells will be needed in order to lower the groundwater level and control inflows ahead of mining operations.

8.3 IMPACTS OF PIT DEWATERING ON GROUNDWATER LEVELS AND SEEPAGE PATHWAYS

Mine inflow (and dewatering) will affect groundwater levels surrounding the pit. The extent of impact is represented by the drawdown (the difference between pre-mining and end of mining groundwater levels) in the water table at the end of mining for the two scenarios.

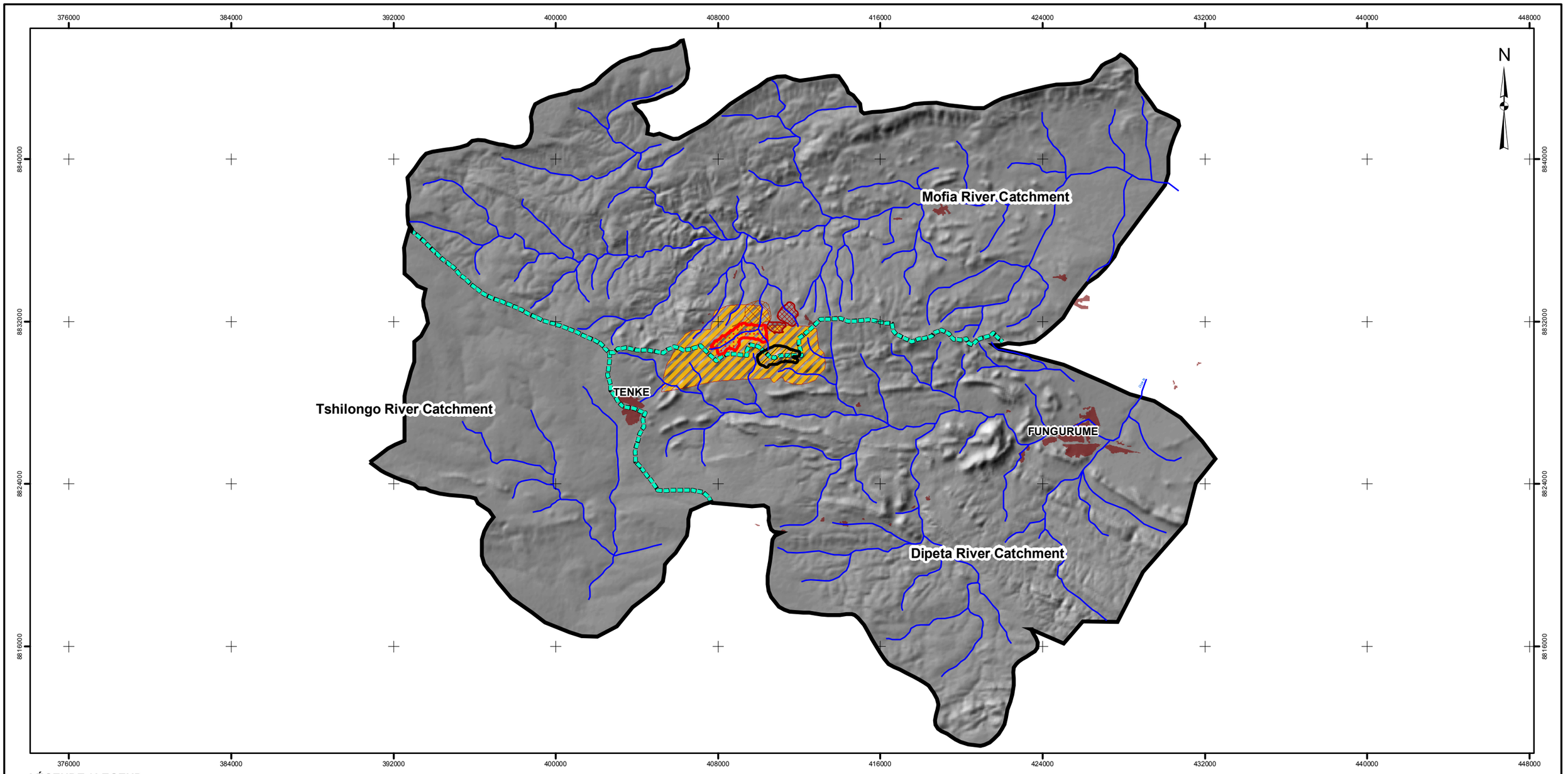
8.3.1 Capture Zone

The area that provides groundwater inflow to the pit (capture zone) was delineated using reverse particle tracking. Particle tracking delineates a path that groundwater follows from recharge to ultimate discharge. Inside the capture zone, groundwater flow is towards and into the open pit while outside the capture zone boundary, all groundwater flow is away from the open pit. The capture zone for the open pit is presented as a hashed area on Figures 29 and 30 for the two scenarios assuming a storativity of three percent (the mid-value of the range). All groundwater recharge (and any seepage from mine facilities) inside this area will flow towards the pit and enter the pit dewatering system.

The fate of groundwater recharge from mine facilities (such as a leak from the tailings storage facility) was evaluated by forward particle tracking (i.e., observing the flow path of groundwater from recharge to ultimate discharge either into the pit or to surface water).

As part of the sensitivity analysis, the capture zone was also determined based on the modified mine plan. The results are shown on Figures 29a and 30a for Scenarios 1 and 2, respectively. The figures show that the capture zones are slightly larger as a result of the greater pit footprint assumed for the modified dewatering plan.

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Capture Zone 1B Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Capture Zone 1B Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- MODELLED AREA
- CATCHMENT DIVIDE
- CAPTURE ZONE
- RIVER

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
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TITRE
TITLE

CAPTURE ZONE OF MINE PIT AT END OF MINING SCENARIO 1 (STORATIVITY = 3%)

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
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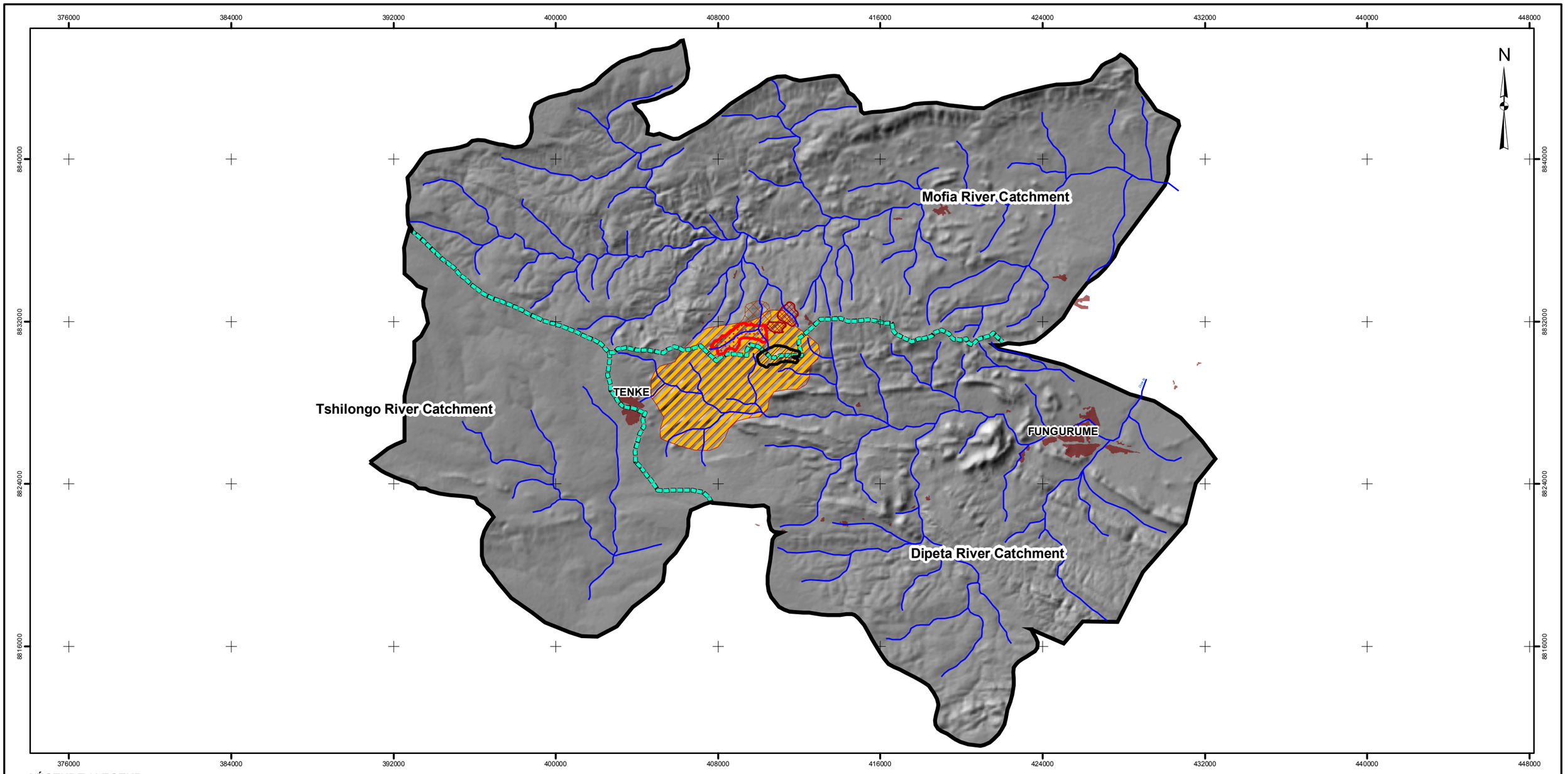
VÉRIFIÉ / CHECK	HvR	Mar 2007		
APPROUVÉ / REVIEW	DB	Mar 2007		

FIGURE: 29

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Capture Zone 1B.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Capture Zone 1B.pdf



LÉGENDE / LEGEND

- CAPTURE ZONE
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- MODELLED AREA
- CATCHMENT DIVIDE
- RIVER

3 0 3 6 9 12 15

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SCALE 1:190,000 KILOMETRES

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TITRE
TITLE

CAPTURE ZONE OF MINE PIT AT END OF MINING SCENARIO 1 SENSITIVITY ANALYSIS

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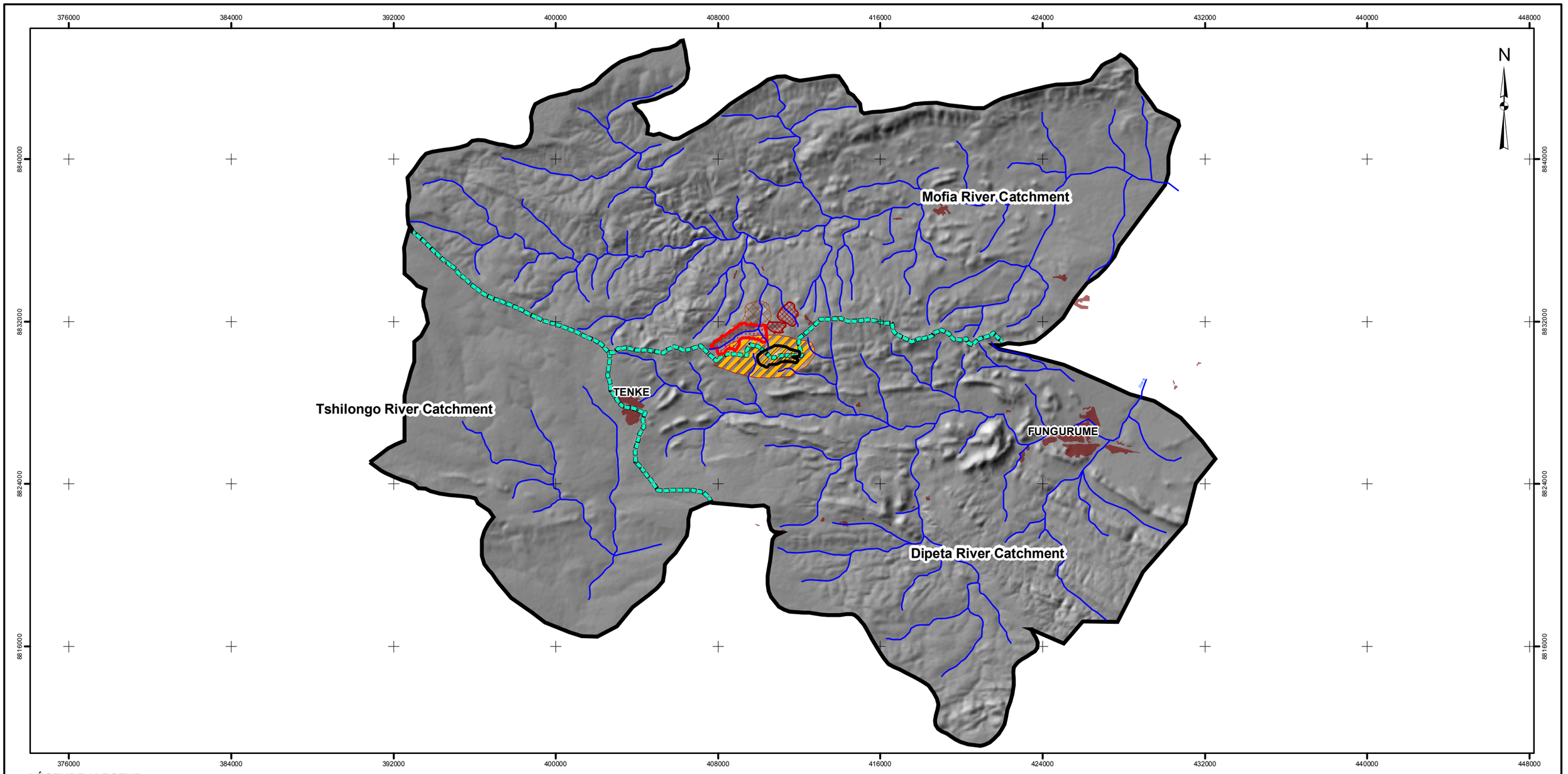
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 29a

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Capture Zone 2B.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Capture Zone 2B.pdf



LÉGENDE / LEGEND

- CAPTURE ZONE
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- MODELLED AREA
- CATCHMENT DIVIDE
- RIVER

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

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TITRE
TITLE

CAPTURE ZONE OF MINE PIT AT END OF MINING SCENARIO 2 (STORATIVITY = 3 %)

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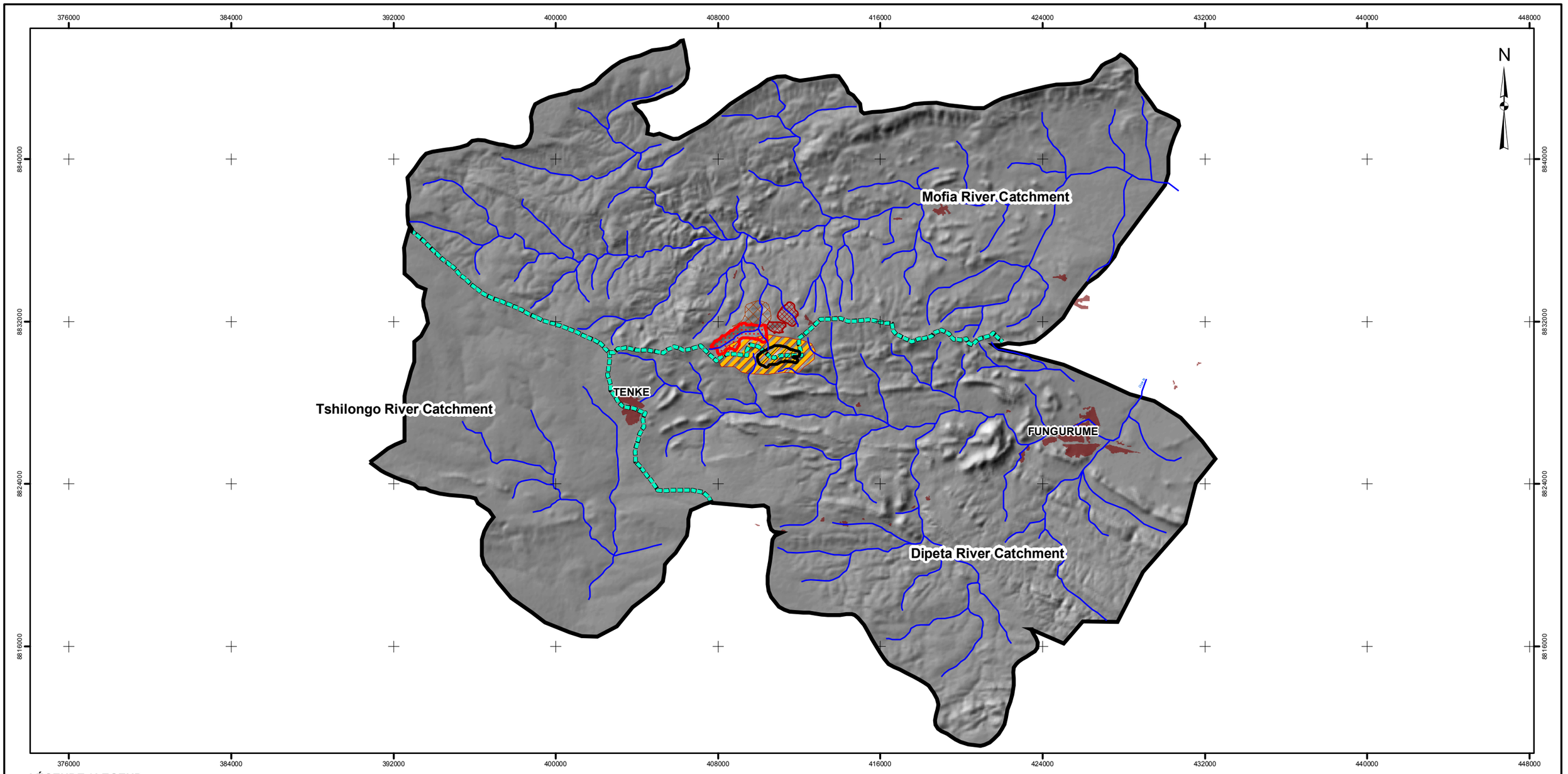
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 30

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Capture Zone 2B Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Capture Zone 2B Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- CAPTURE ZONE
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- MODELLED AREA
- CATCHMENT DIVIDE
- RIVER

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

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CAPTURE ZONE OF MINE PIT AT END OF MINING SCENARIO 2 SENSITIVITY ANALYSIS

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APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 30a

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

8.3.2 Changes in Groundwater Elevations

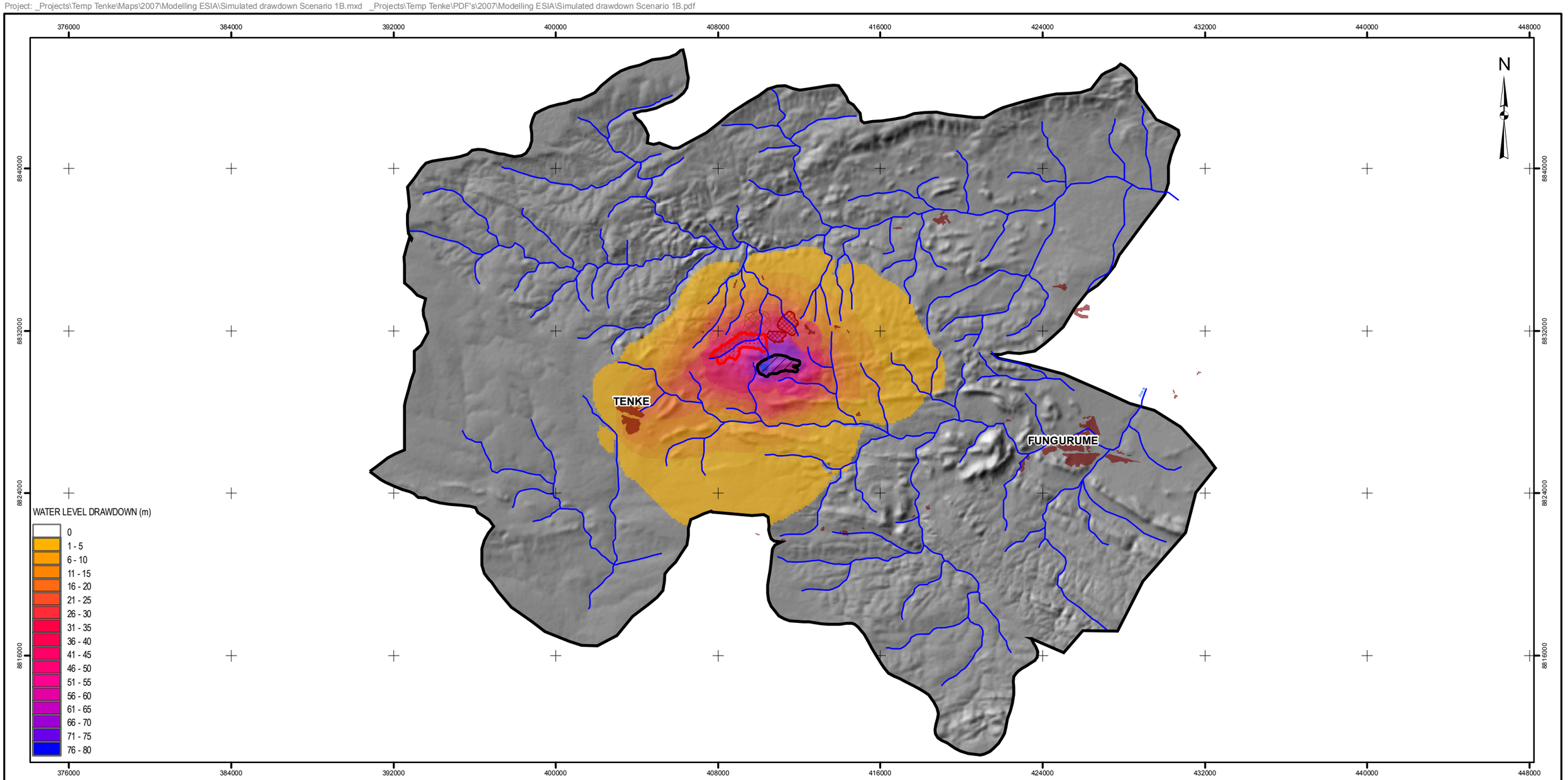
8.3.2.1 Scenario 1

Figures 31 and 31a shows the drawdown when the pit has been mined to a depth of 80 meters below the water table for Scenario 1 for a storativity of three percent,. The area affected by at least one meter or more of drawdown is 160 square kilometers.

The simulated groundwater elevation at the end of mining is depicted in Figures 32 and 32a for a storativity of three percent.

Prior to dewatering, groundwater will flow according to the natural undisturbed groundwater level distribution. The flow paths of groundwater seepage from the mine facilities were determined by forward tracking of particles as shown on Figure 33. An effective porosity of one percent has been used as representing the worst case in terms of travel distance of a potential contaminant. The distance between the symbol markings on the particle traces of Figures 33 and 33a show the horizontal distance traveled in 1, 2, 4, 8, and 12 years.

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated drawdown Scenario 1B.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated drawdown Scenario 1B.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

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SIMULATED DRAWDOWN AT THE END OF MINING SCENARIO 1 (STORATIVITY = 3%)

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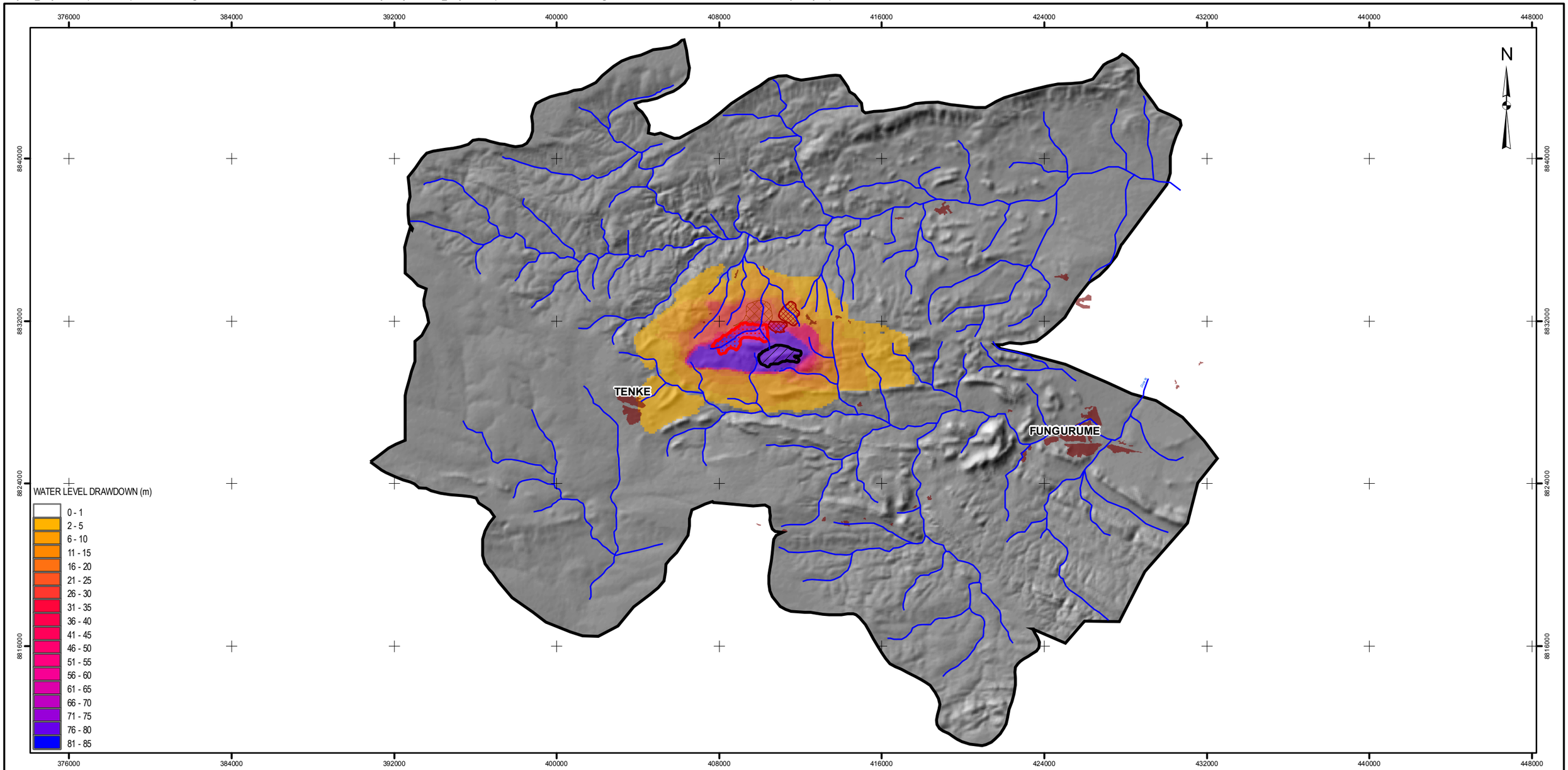
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated drawdown Scenario 1B Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated drawdown Scenario 1B Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

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FIGURE: 31a

RÉFÉRENCE / REFERENCE

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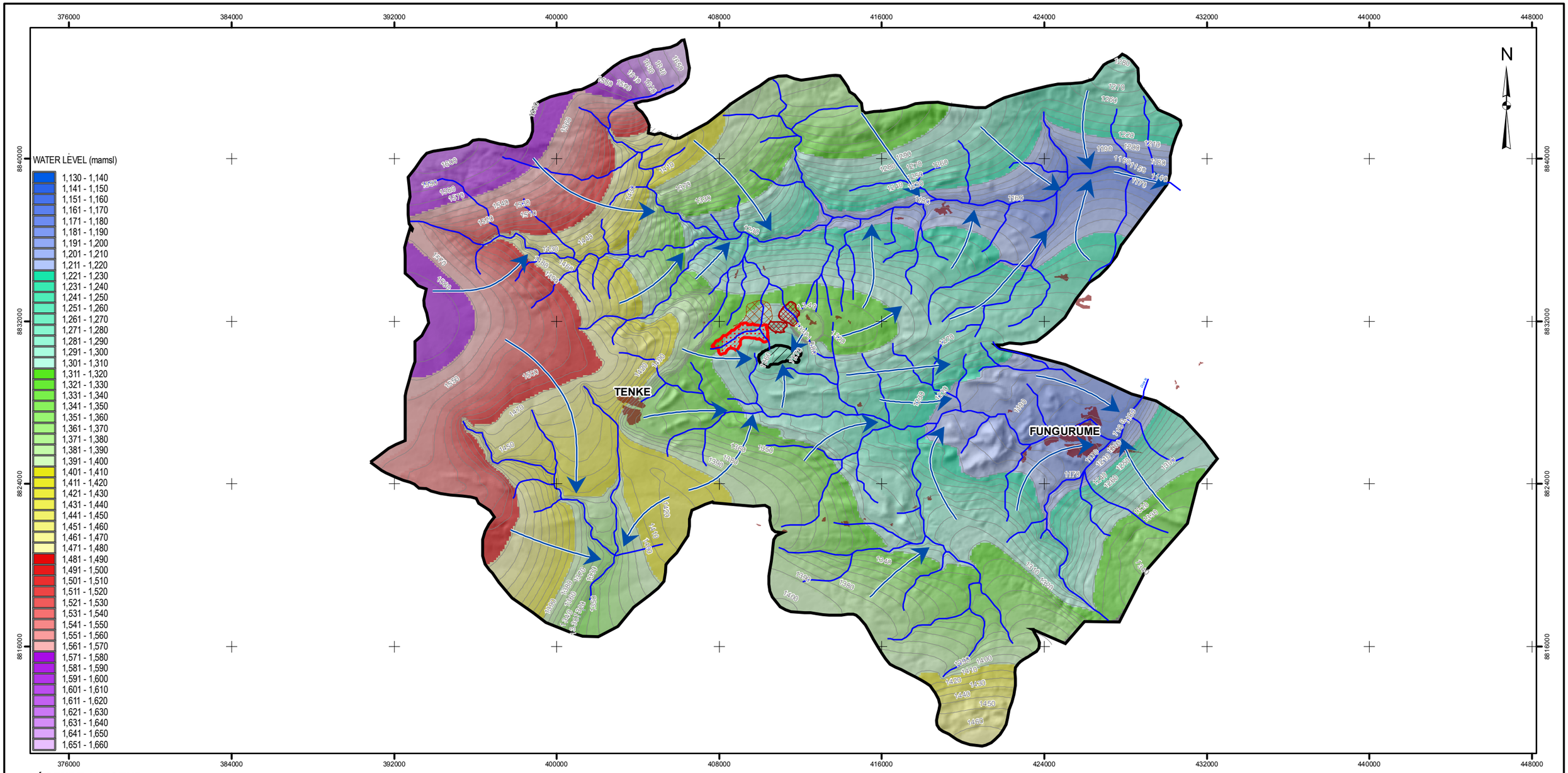


LÉGENDE / LEGEND

- GROUNDWATER FLOW DIRECTION
- WATER LEVEL CONTOUR (mamsl)
- RIVER
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

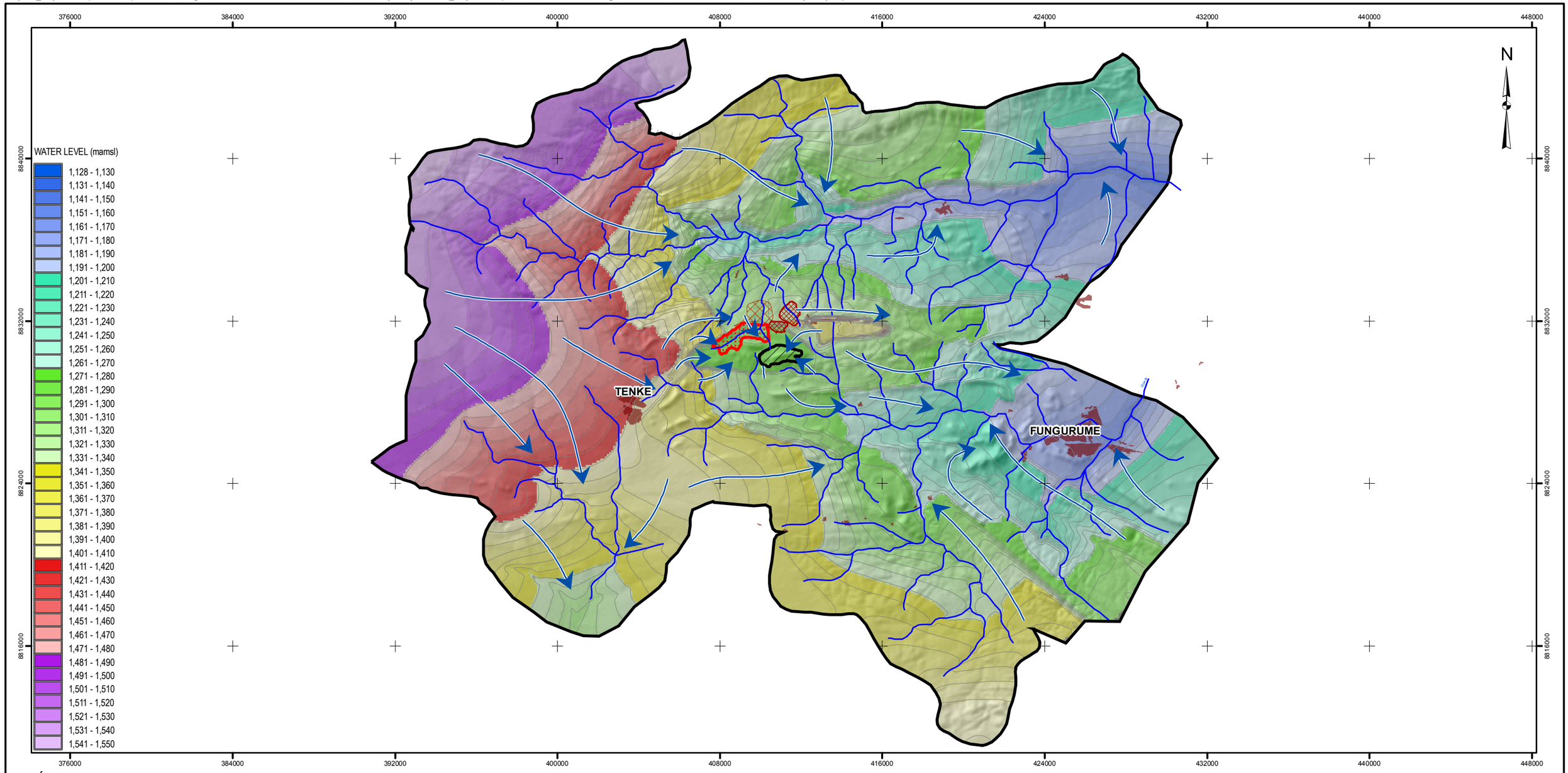
TITRE / TITLE

SIMULATED GROUNDWATER LEVELS AT THE END OF MINING SCENARIO 1 (STORATIVITY = 3 %)

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	FIGURE: 32	
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated water levels Scenario 1B Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated water levels Scenario 1B Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- GROUNDWATER FLOW
- WATER LEVEL CONTOUR (mamsl)
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000KILOMÈTRES
SCALE 1:190,000KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

SIMULATED GROUNDWATER LEVELS AT THE END OF MINING SCENARIO 1 SENSITIVITY ANALYSIS

Golder Associates
Johannesburg, South Africa

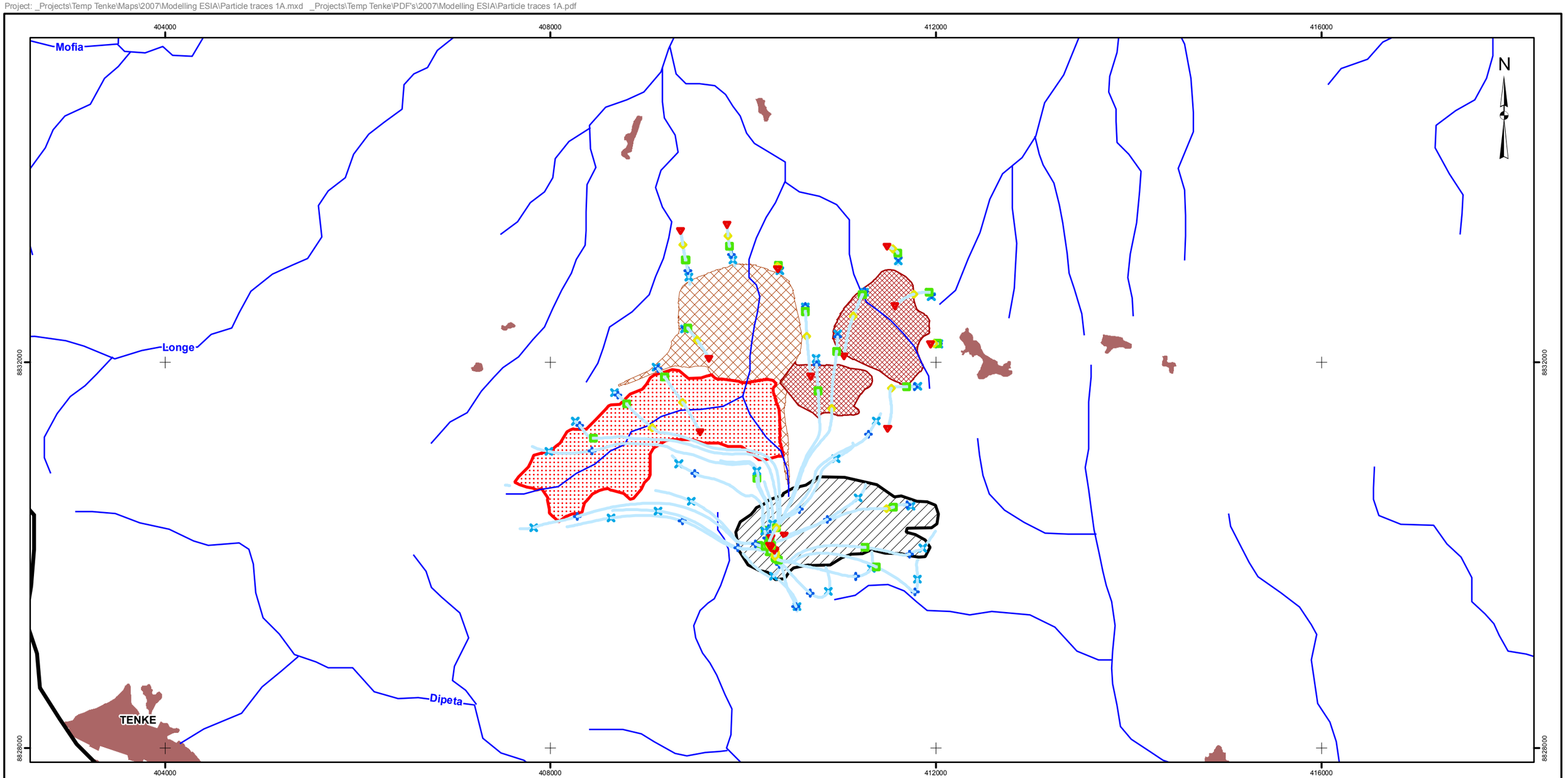
N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 32a

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Particle traces 1A.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Particle traces 1A.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PARTICLE TRACE

TIME

- 360 days
- 720 days
- 1440 days
- 2880 days
- 4320 days
- Flow path

0.5 0 0.5 1 1.5 2 2.5 3

ÉCHELLE 1:40,000 KILOMÈTRES
SCALE 1:40,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

PARTICLE TRACES FOR SCENARIO 1 (MINING PHASE)

Golder Associates
Johannesburg, South Africa

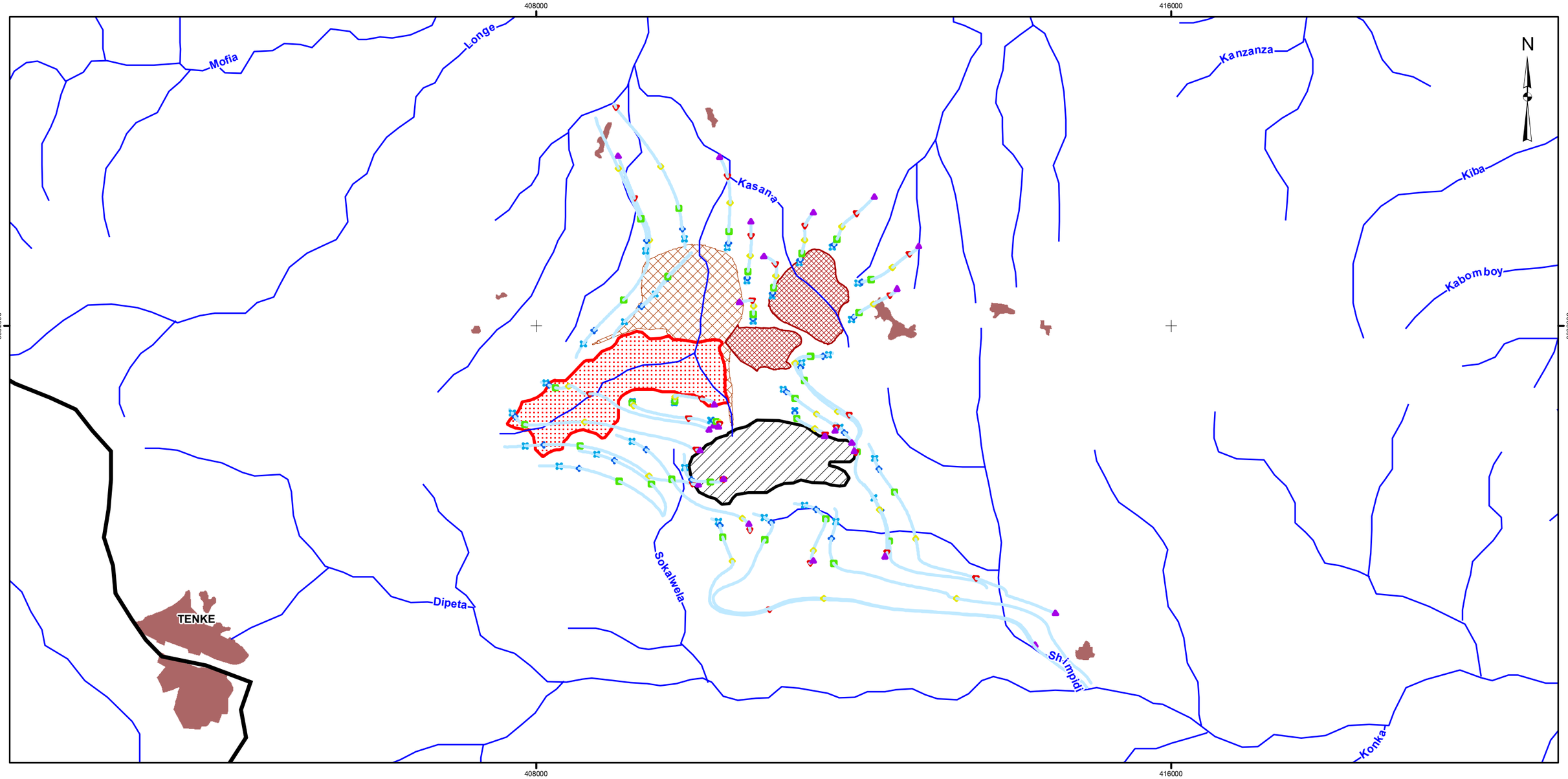
N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 33

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Particle traces 1A Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Particle traces 1A Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PARTICLE TRACE

TIME

- 360 days
- 720 days
- 1440 days
- 2880 days
- 4320 days
- 5760 days
- Flow path

0.75 0 0.75 1.5 2.25 3 3.75

ÉCHELLE 1:50,000 KILOMÈTRES
SCALE 1:50,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

PARTICLE TRACES FOR SCENARIO 1 (MINING PHASE) SENSITIVITY ANALYSIS

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	**FIGURE: 33a**	
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Figure 33 indicates that seepage from the tailings facility and the southern part of the waste rock facilities and southwest ore stockpiles will migrate to the south and southeast (towards the Kwatebala pit) prior to dewatering commencing while seepage from the northern parts of the waste rock facilities and stockpiles will migrate towards the north and the Mofia River. The groundwater travel time to the Mofia River and the Kasana River tributary varies from less than one year where the stockpile is located in a valley bottom and there is the potential for a discharge to the headwater tributaries to over 20 years where groundwater discharge is to the lower reaches of the Kasana or to the Mofia rivers.

The open pit capture zone at the end of mining determined from backward particle tracking depicted in Figure 29 shows that seepage from the tailings facility will be captured by the pit but recharge from parts of the waste rock facilities and stock piles will migrate to the Mofia River in the north.

8.3.2.2 Scenario 2

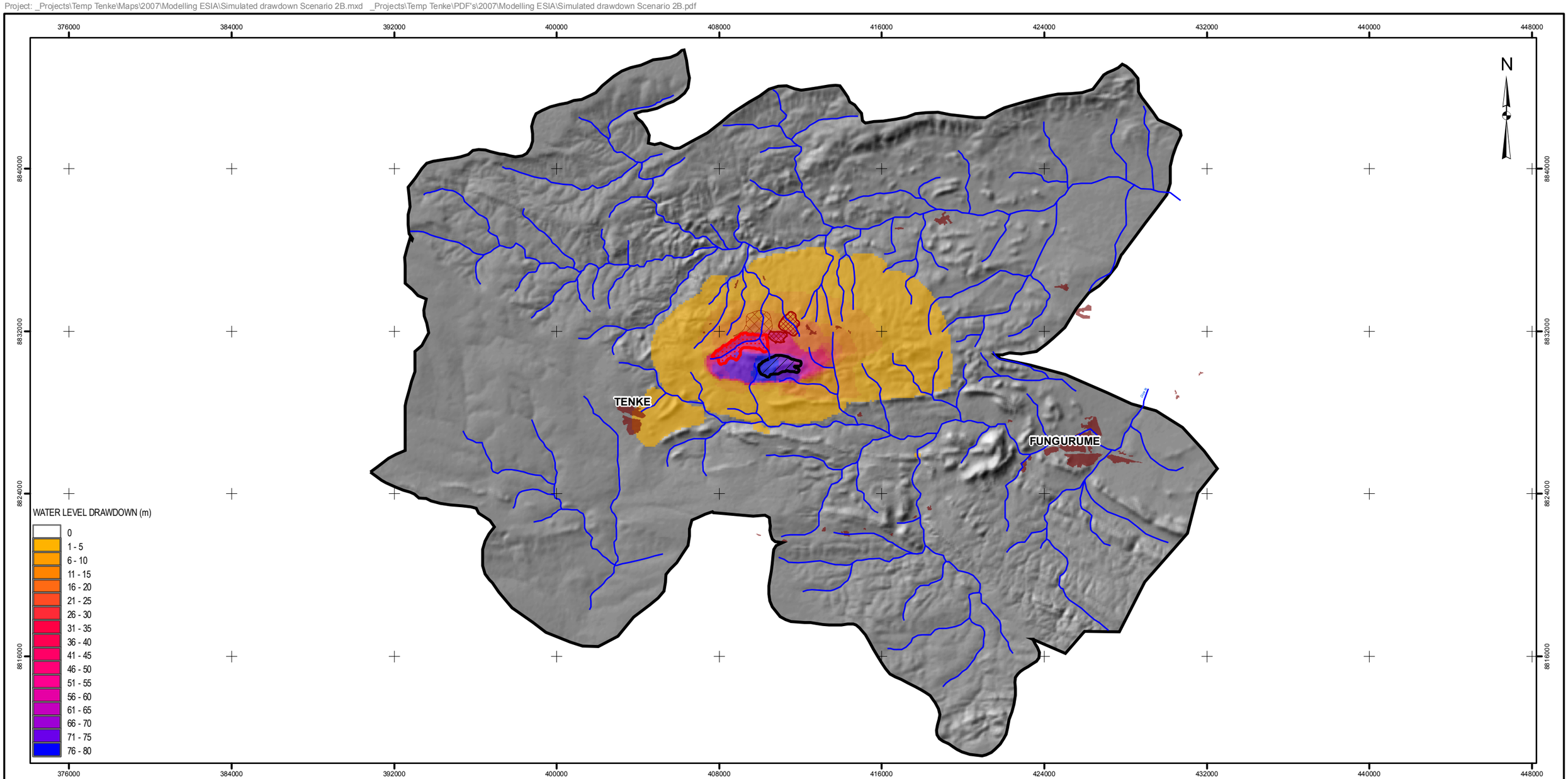
Figures 34 and 34a, show the drawdown when the pit has been mined to 80 meters below the water table for a storativitity of three percent. The area affected by one meter or more of drawdown is 103 square kilometers. The simulated groundwater elevations at the end of mining are depicted in Figures 35 and 35a.

Prior to dewatering groundwater will flow according to the natural undisturbed groundwater level distribution. The flow paths of groundwater seepage from the mine facilities were determined by forward tracking of particles as shown on Figures 36 and 36a. An effective porosity of one percent has been used as representing the worst case in terms of travel distance of a potential contaminant. The distance between the symbol markings on the particle traces of Figure 36 show the horizontal distance traveled in 1, 2, 4, 8, and 12 years.

Figures 36 and 36a indicates that seepage from the tailings facility and the southern part of the waste rock facilities and ore stockpiles will migrate to the south and southeast (towards the Kwatebala pit) prior to dewatering commencing while seepage from the northern parts of the waste rock facilities and stockpiles will migrate towards the north and the Mofia River. Groundwater travel times from the stockpiles to surface water are predicted to range from less than a year (where there is the potential for a flowpath to discharge in headwater tributaries of the Kasana River), to about 16 years to the Mofia River.

The open pit capture zone at the end of mining determined from backward particle tracking is depicted in Figure 30 shows that seepage from the tailings facility will be captured by the pit but recharge from parts of the waste rock facility and ore stockpiles will migrate to the Mofia River.

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated drawdown Scenario 2B.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated drawdown Scenario 2B.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

SIMULATED DRAWDOWN AT THE END OF MINING SCENARIO 2 (STORATIVITY = 3 %)

RÉFÉRENCE / REFERENCE

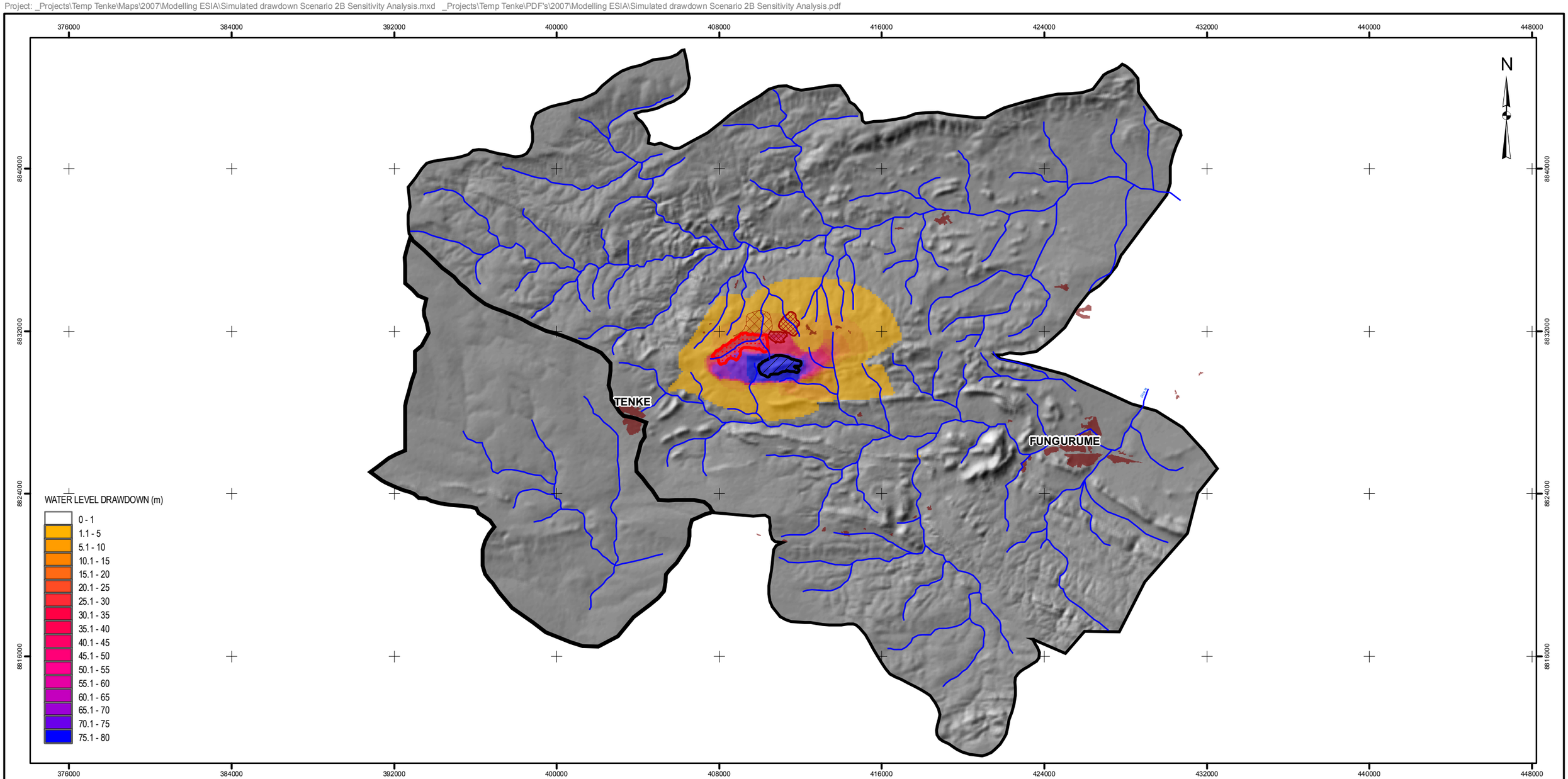
Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN — REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

FIGURE: 34

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated drawdown Scenario 2B Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated drawdown Scenario 2B Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

SIMULATED DRAWDOWN AT THE END OF MINING SCENARIO 2 SENSITIVITY ANALYSIS

Golder Associates
Johannesburg, South Africa

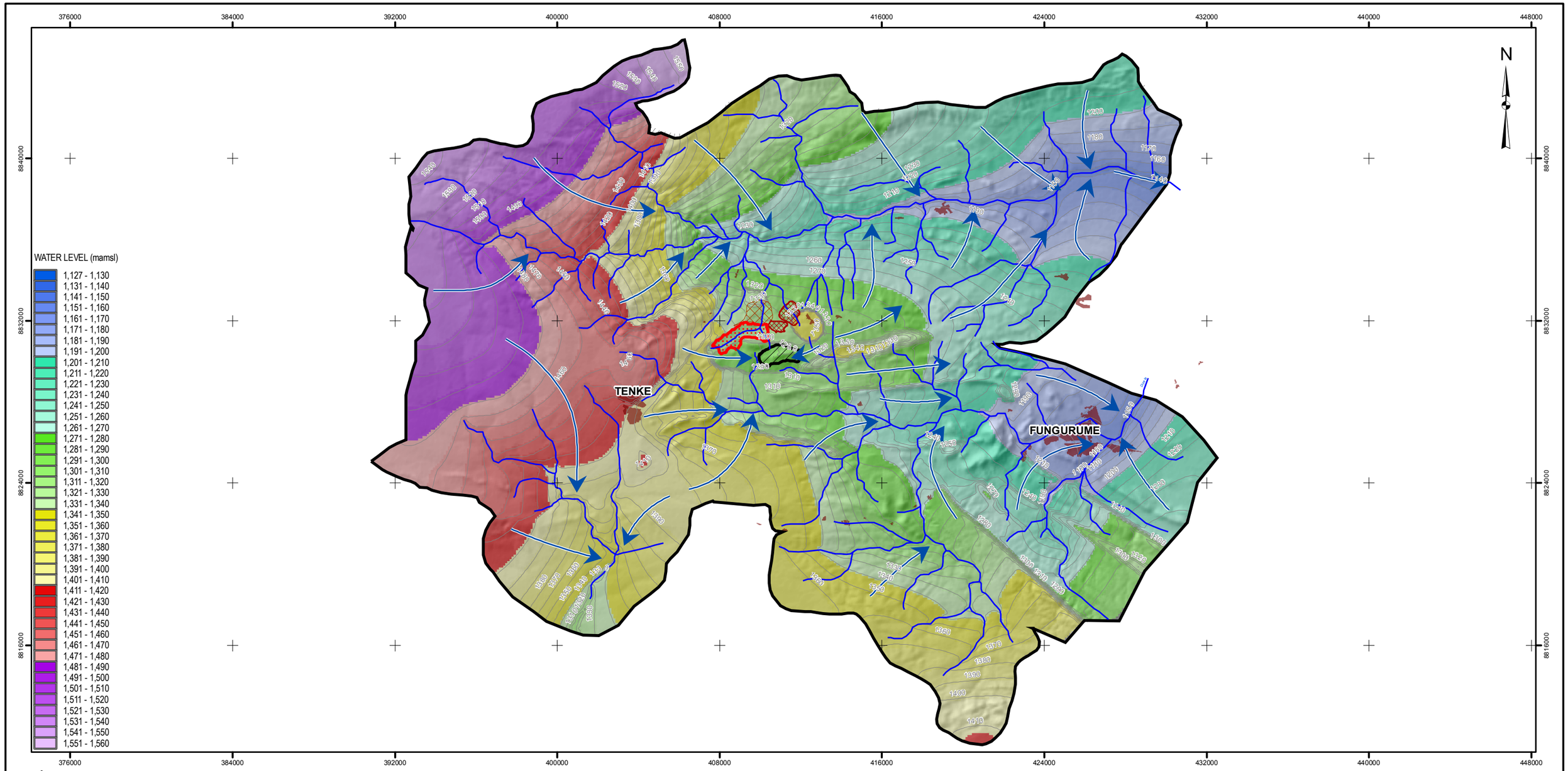
N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ REVIEW	DB	30 Jan 2007		

FIGURE: 34a

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated water levels Scenario 2B.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated water levels Scenario 2B.pdf



LÉGENDE / LEGEND

- GROUNDWATER FLOW DIRECTION
- WATER LEVEL CONTOUR (mamsl)
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3 6 9 12 15

ÉCHELLE 1:190,000KILOMÈTRES
SCALE 1:190,000KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

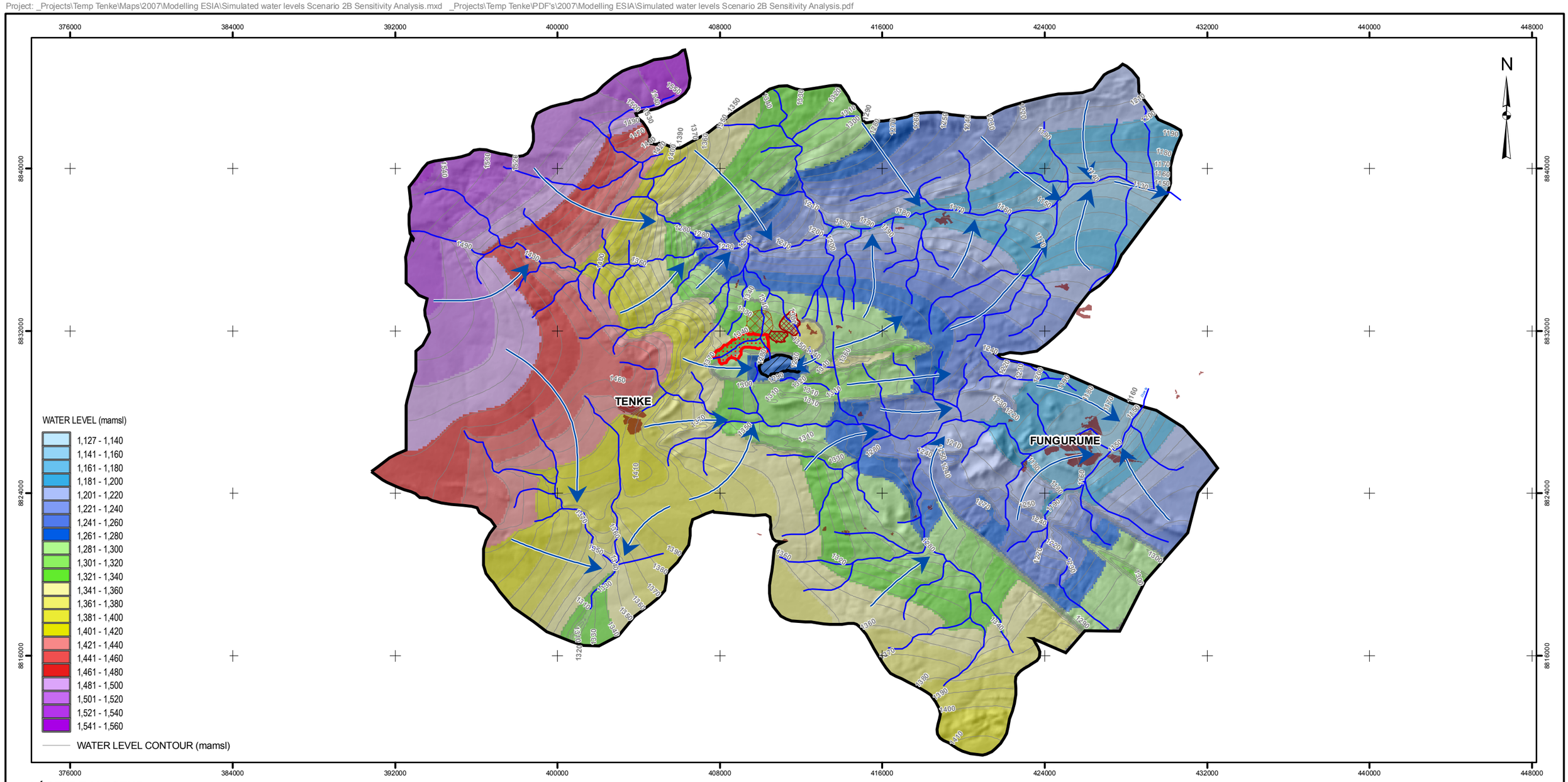
SIMULATED WATER LEVELS AT THE END OF MINING SCENARIO 2 (STORATIVITY = 3 %)

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN — REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

FIGURE: 35

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated water levels Scenario 2B Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated water levels Scenario 2B Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- GROUNDWATER FLOW
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

SIMULATED WATER LEVELS AT THE END OF MINING SCENARIO 2 SENSITIVITY ANALYSIS

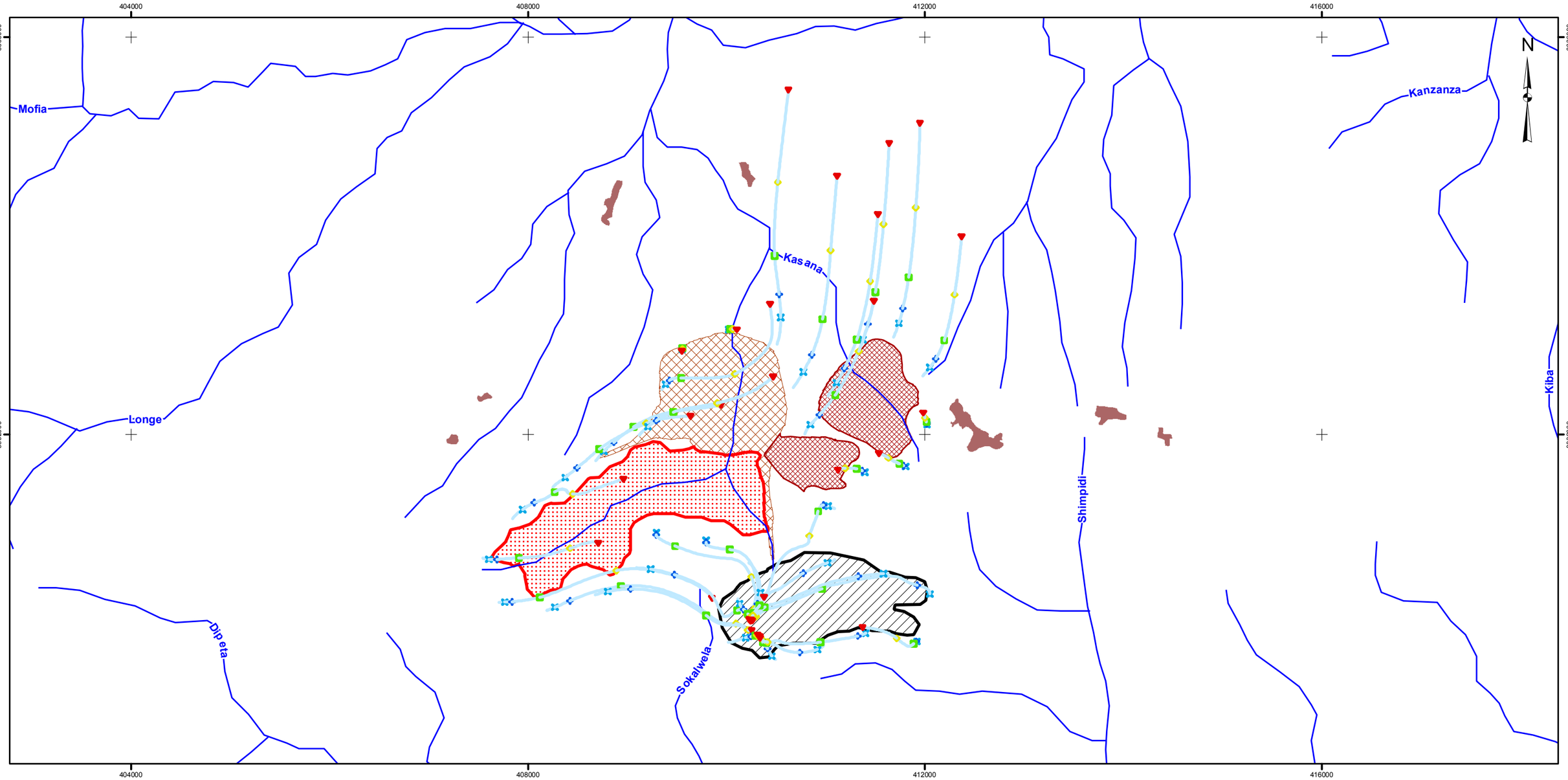
Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	FIGURE: 35a	
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Particle traces 2A.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Particle traces 2A.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PARTICLE TRACE

TIME

- 360 days
- 720 days
- 1440 days
- 2880 days
- 4320 days
- Flow path

0.5 0 0.5 1 1.5 2 2.5 3

ÉCHELLE 1:40,000 KILOMÈTRES
SCALE 1:40,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

PARTICLE TRACES FOR SCENARIO 2 (MINING PHASE)

Golder Associates
Johannesburg, South Africa

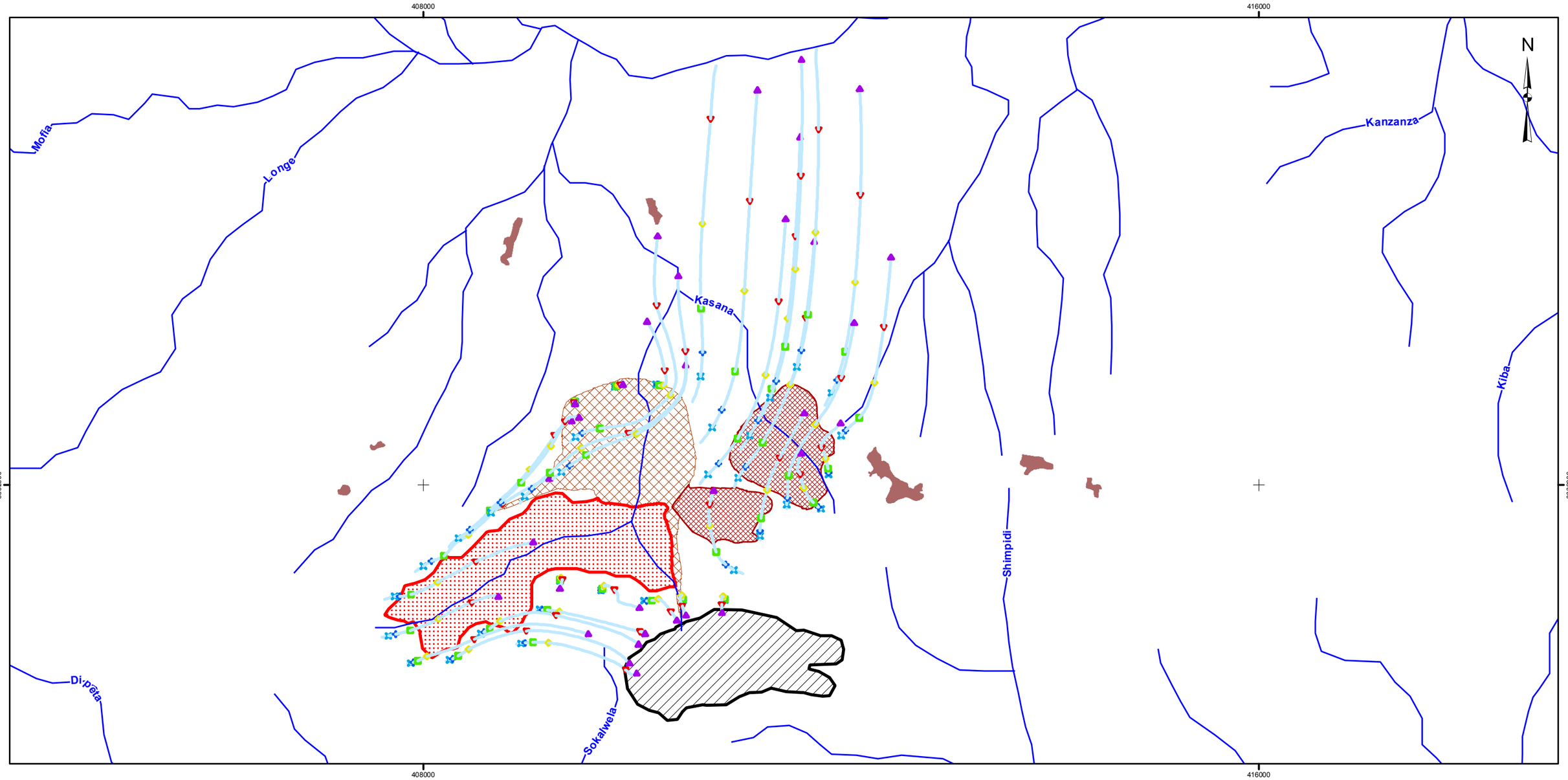
N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN / REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

FIGURE: 36

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

_Projects\Temp Tenke\Maps\Modelling Jan 2007\Forward track particle traces Scenario 2 Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling Jan 2007\Forward track particle traces Scenario 2 Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PARTICLE TRACE TIME

- 360 days
- 720 days
- 1440 days
- 2880 days
- 4320 days
- 5760 days
- Flow path

0.6 0 0.6 1.2 1.8 2.4 3

ÉCHELLE 1:38,000 KILOMÈTRES
SCALE 1:38,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

PARTICLE TRACES FOR SCENARIO 2 (MINING PHASE) SENSITIVITY ANALYSIS

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	FIGURE: 36a
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

8.3.2.3 Sensitivity of Dewatering Impacts to Changes in the Mine Plan

As described in Section 8.2.3.3, in order to evaluate the sensitivity of the dewatering impacts to the dewatering plan, additional simulations were performed using a modified plan. The modified plan is discussed in Section 8.2.3.3.

The two geological scenarios were modeled. The effects of dewatering on the regional groundwater elevations are presented on Figure 32a and 35a for a storativity of three percent. The results show that the areas affected by one meter or more of drawdown are 131 and 80 square kilometers for Scenarios 1 and 2, respectively. This is in the order of 20 to 30 percent smaller than for the baseline mine plan where the areas affected are 160 and 103 square kilometers for Scenarios 1 and 2, respectively. The reason for the smaller areas affected is as a result of the smaller quantities of groundwater pumped under the modified dewatering plan over the dewatering period (8 years versus 12 years). The simulated groundwater elevations at the end of mining are depicted in Figure 32a and Figure 36a.

The effects of dewatering on the groundwater flow paths from the tailings facility and waste rock and ore stockpiles are shown on Figures 33a and 36a for the two scenarios. These figures show the pathlines from these facilities during the operational mining phase. An effective porosity of one percent has been used as representing the worst case in terms of travel distance of a potential contaminant. The distance between the symbol markings on the particle traces show the horizontal distance traveled in 1, 2, 4, 8, and 12 years.

Figure 33a shows that seepage emanating from the tailings facility, southern parts of the waste rock facility and ore stockpile will be intercepted by the dewatering system under Scenario 1. Seepage from the northern parts of the waste rock stockpile and ore stockpile will not be intercepted by the dewatering activities. Seepage would migrate slowly northward (about 600 meters after 12 years).

Figure 36a shows that seepage from the southern portions of the tailings facility will be intercepted by the dewatering activities from the mine pit under Scenario 2. Seepage from the northern parts of the tailings facility, waste rock facility and ore stockpile will not be intercepted by the dewatering activities from the mine pit. Seepage would migrate northward traveling about 2,500 meters after 12 years.

8.3.2.4 Summary

The two scenarios demonstrate a range of likely groundwater flow paths for seepage from the tailings, waste rock stockpile and ore stockpiles. Under Scenario 2, seepage from the waste rock and ore stockpiles moves under a higher groundwater velocity towards the Mofia River. This is because the pit dewatering effects are limited in their spread northward by the low permeability units representing the topographically-higher area of the model domain.

In the ESIA, the estimates of groundwater travel time developed using the two scenarios have been used in conjunction with analytical transport modeling to estimate the groundwater discharge concentrations reaching surface water.

8.4 POST-CLOSURE GROUNDWATER FLOW CONDITIONS

Subsequent to the mining phase the model was run to steady state to simulate the recovery of the groundwater levels for both Scenarios 1 and 2.

The post-closure modeling assumed a storativity of three percent. At the end of mining, the hydraulic parameters representing the open pit were set to that of open void conditions (storativity = 100 percent in Layers 1 and 2) representing the mined-out material. The hydraulic conductivity values were set to 86.4 meters/day (Layers 1 and 2). (A large hydraulic conductivity value is required by the model to attain a horizontal pit lake water level in the open pit). Recharge across the open pit was subsequently set to 40 percent of MAP compared to the surrounding aquifer recharge of 20 percent of MAP.

The post-closure impacts on the hydrogeological regime of the study area were determined by subtracting the groundwater level after 16 years of mine closure or at post-closure steady state from the pre-mining steady state groundwater level. This is presented as drawdown from the pre-mining steady state groundwater elevation.

8.4.1 Mine Flooding

8.4.1.1 Scenario 1

Figures 37 and 37a shows the recovery of water levels within the Kwatebala open pit following mining. The water level recovers to a new equilibrium level (a few meters below the pre-mining groundwater level) about 20 years after the end of mining.

Figure 37 Simulated Water Level in Kwatebala Open Pit Following Mining – Scenario 1

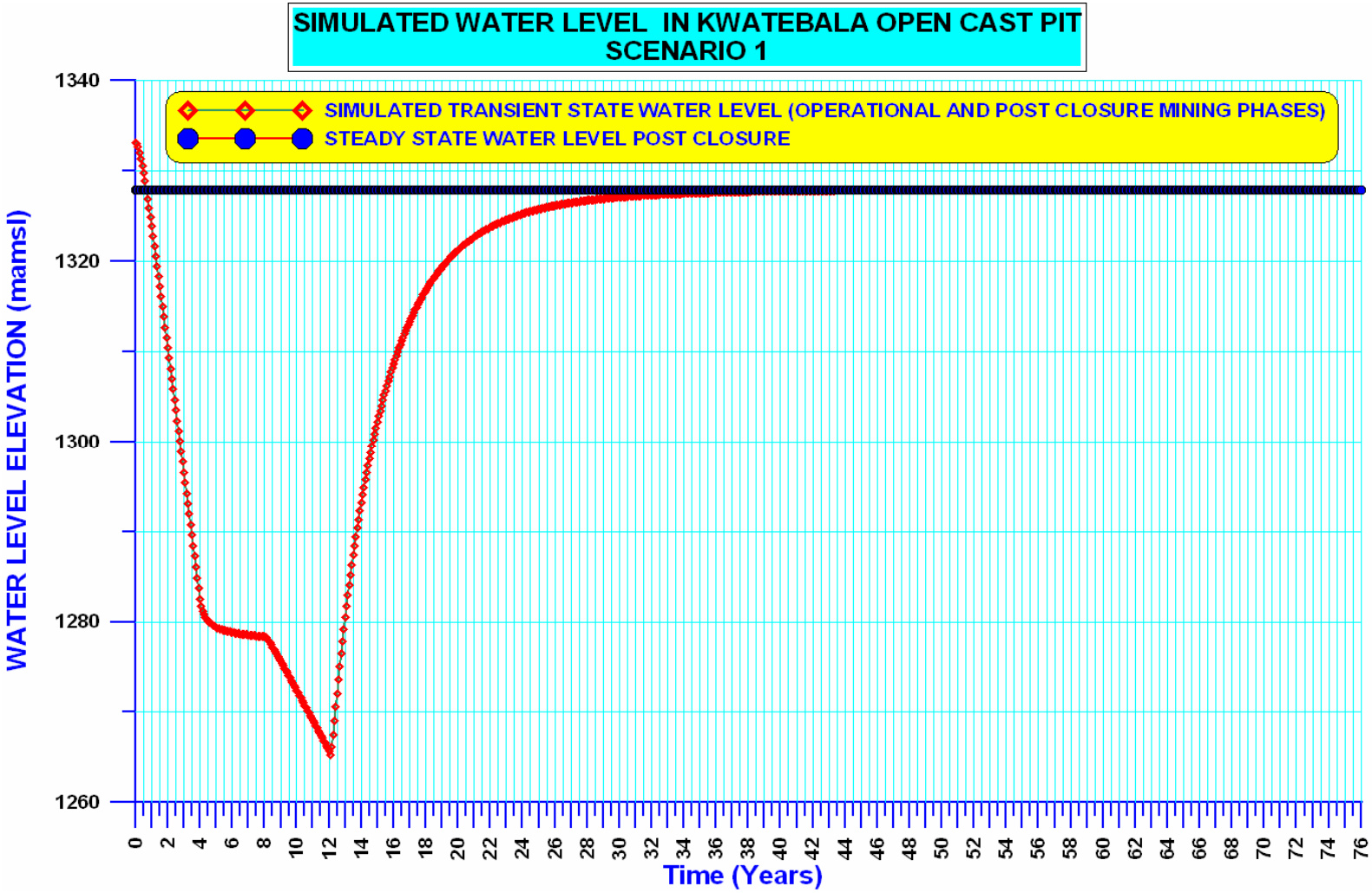
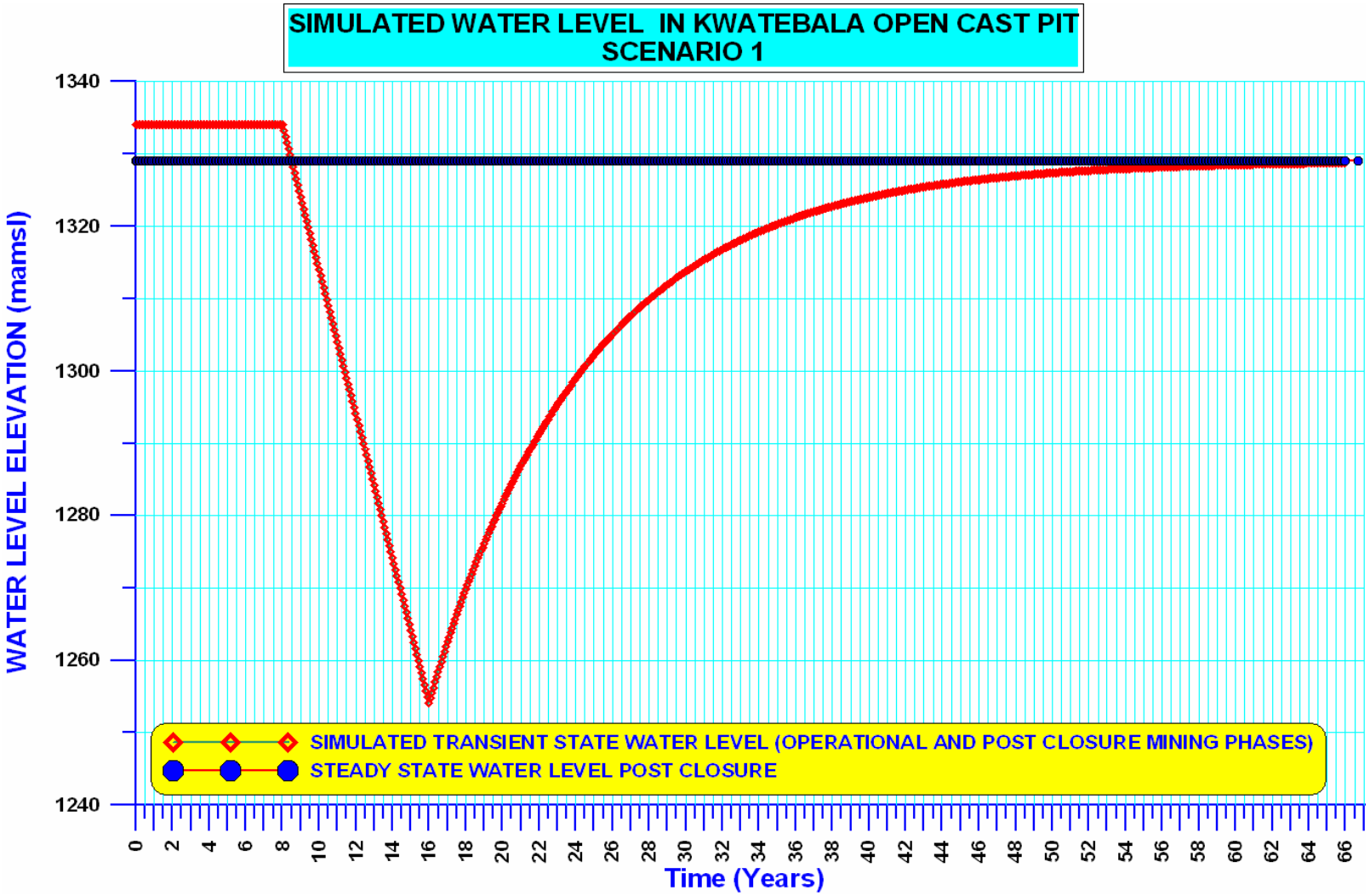


Figure 37a **Simulated Water Level in Kwatebala Open Pit Following Mining – Scenario 1 – Sensitivity Analysis**



8.4.1.2 Figure 38 Scenario 2 Impact

Figure 38 shows the recovery of water levels within the Kwatebala open pit following mining. The water level recovers to a new equilibrium level (a few meters below the pre-mining groundwater level) about 60 years following the end of mining. The slower recovery is because of the lower rate of groundwater inflow into the pit under this scenario.

8.4.1.3 Sensitivity Analysis

A sensitivity analysis of the post-closure pit water level was completed. Figures 37a and 38a present the water level recovery in the pit. Water levels recover more slowly because of the larger pit volume required to be filled. Time to reach a new steady-state water level ranges from about 40 to about 160 years following the end of mining.

8.4.2 Post-Closure Steady State Conditions

The model was run to steady state to determine the long-term changes in the groundwater system from pit dewatering and flooding.

8.4.2.1 Results

Pit Lake

A pit lake will form in the open pit at post-closure as groundwater enters the pit and groundwater levels recover from the effects of dewatering. The modeling indicates that the pit will ultimately be a "through-flow" pit with groundwater entering the pit on the up-gradient side and exiting on the down-gradient side and flowing toward the Dipeta and Mofia rivers and their tributaries. The time for the pit lake to begin discharging to groundwater (through-flow) ranges from about 4 years under Scenario 1 to about 12 years under Scenario 2. Quasi-steady state conditions for the pit lake would be reached after about 20 years for Scenario 1 and after approximately 60 years for Scenario 2.

Figure 38 Simulated Water Level in Kwatebala Open Pit Following Mining – Scenario 2

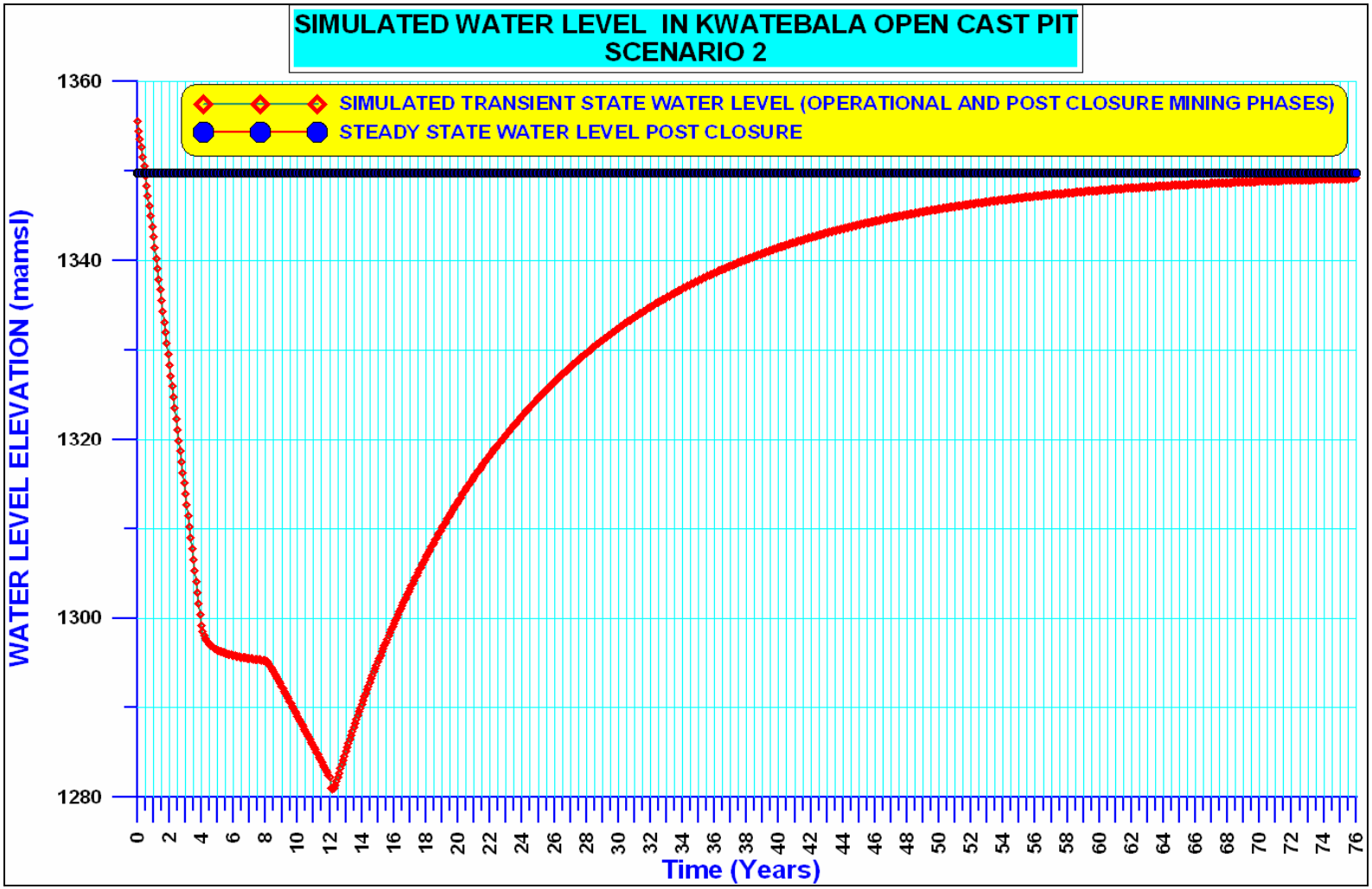
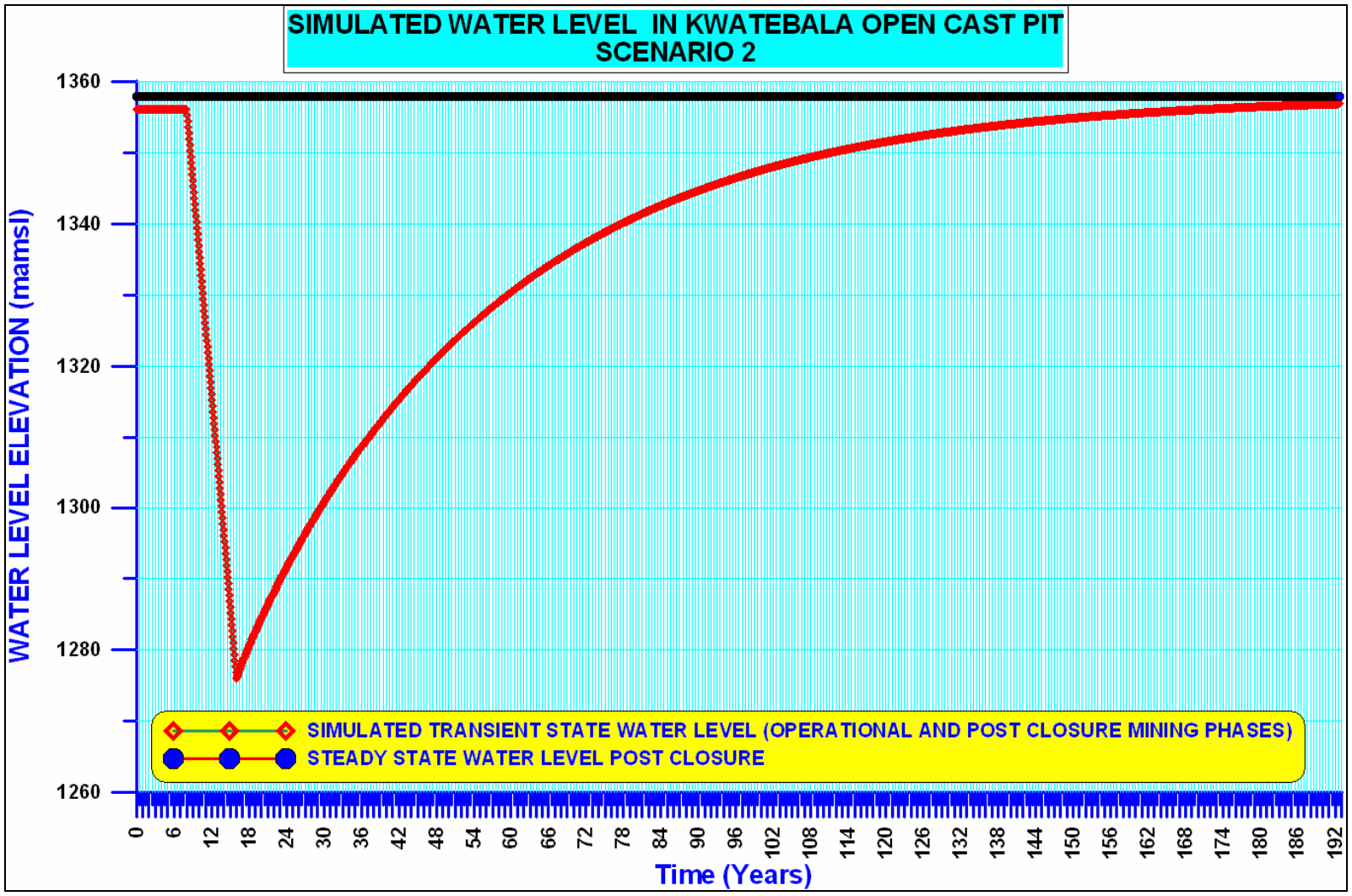


Figure 38a Simulated Water Level in Kwatebala Open Pit Following Mining – Scenario 2 – Sensitivity Analysis



Pit Lake Water Balance

The groundwater outflow from the Kwatebala pit at post-closure steady-state was determined using the "Fluid Flux Analyser" of the FEFLOW modeling package. Results for Scenario 1 and 2 are as follows:

Scenario 1:

The total groundwater outflow from the Kwatebala Pit = 8,500 cubic meters per day.

This outflow is made up as follows:

1. Lateral groundwater throughflow from upstream catchment areas = 6,400 cubic meters per day.
2. Recharge across the pit areas = 2,100 cubic meters per day.

Scenario 2:

The total groundwater outflow from the Kwatebala Pit = 2,700 cubic meters per day.

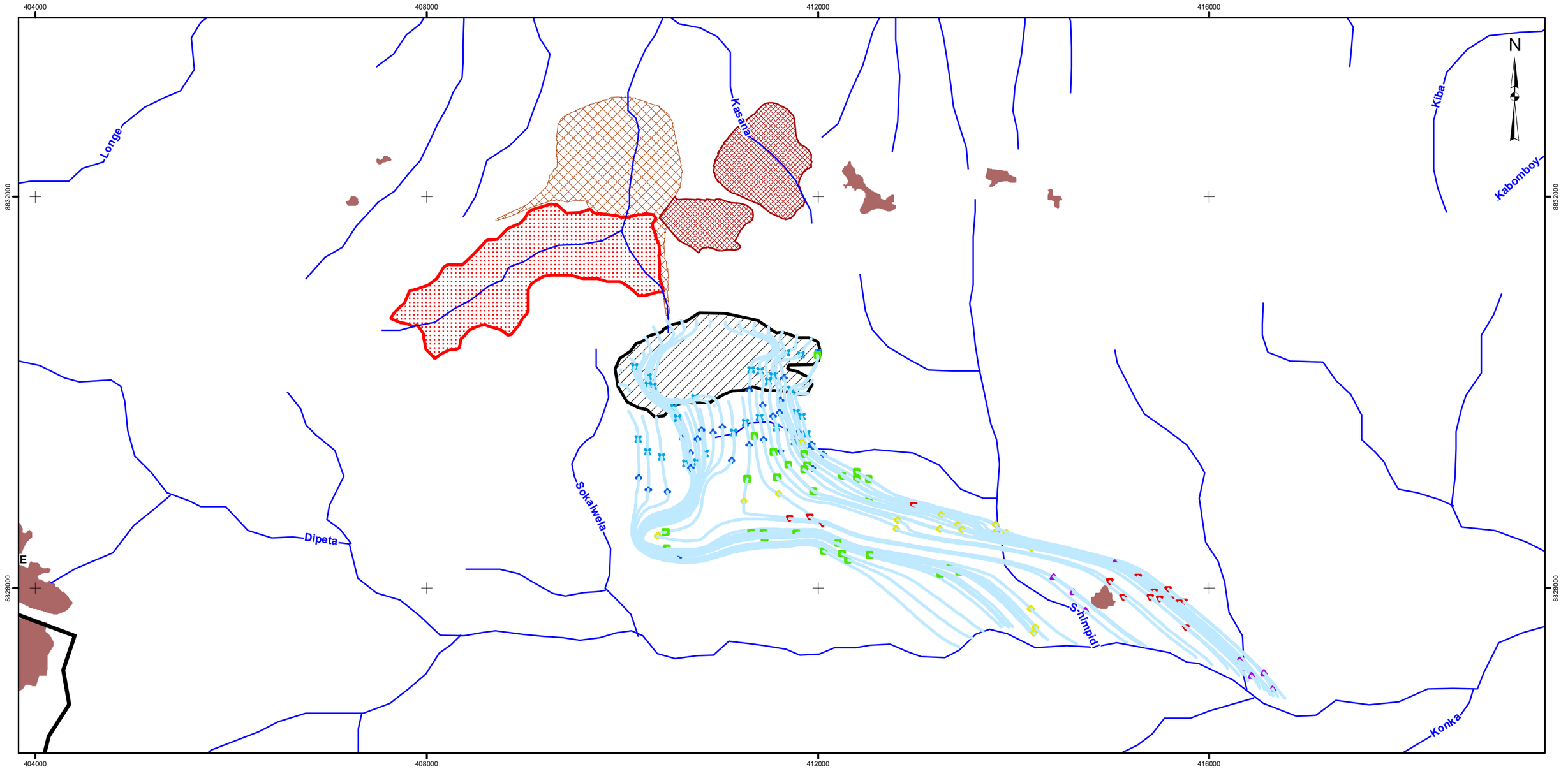
This outflow is made up as follows:

1. Lateral groundwater throughflow from upstream catchment areas = 600 cubic meters per day.
2. Recharge across the pit areas = 2,100 cubic meters per day.

Seepage Pathways from Pit Lake

Particle tracking was used to determine the pathways of seepage from the pit lake post-closure (Figures 39, 39a, 40 and 40a). The horizontal distance traveled using the steady state simulated groundwater flow field is also indicated on the particle trace figures. An effective porosity of one percent has been used as representing the worst case in terms of travel distance of a potential contaminant. As an illustration the distance between the symbol markings on the particle traces of Figures 39 and 40 show the horizontal distance traveled in 1, 2, 4, 8, 12 and 16 years after steady state flow conditions have been established.

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Particle traces Steady state Scenario 1.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Particle traces Steady state Scenario 1.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PARTICLE TRACE

TIME

- 360 days
- 720 days
- 1440 days
- 2880 days
- 4320 days
- 5760 days
- Flow path

0.5 0 0.5 1 1.5 2 2.5 3

ÉCHELLE 1:40,000 KILOMÈTRES
SCALE 1:40,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
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TENKE FUNGURUME MINING SARL

TITRE / TITLE

STEADY STATE PARTICLE TRACES FROM THE KWATEBALA PIT AT POST CLOSURE (SCENARIO 1)

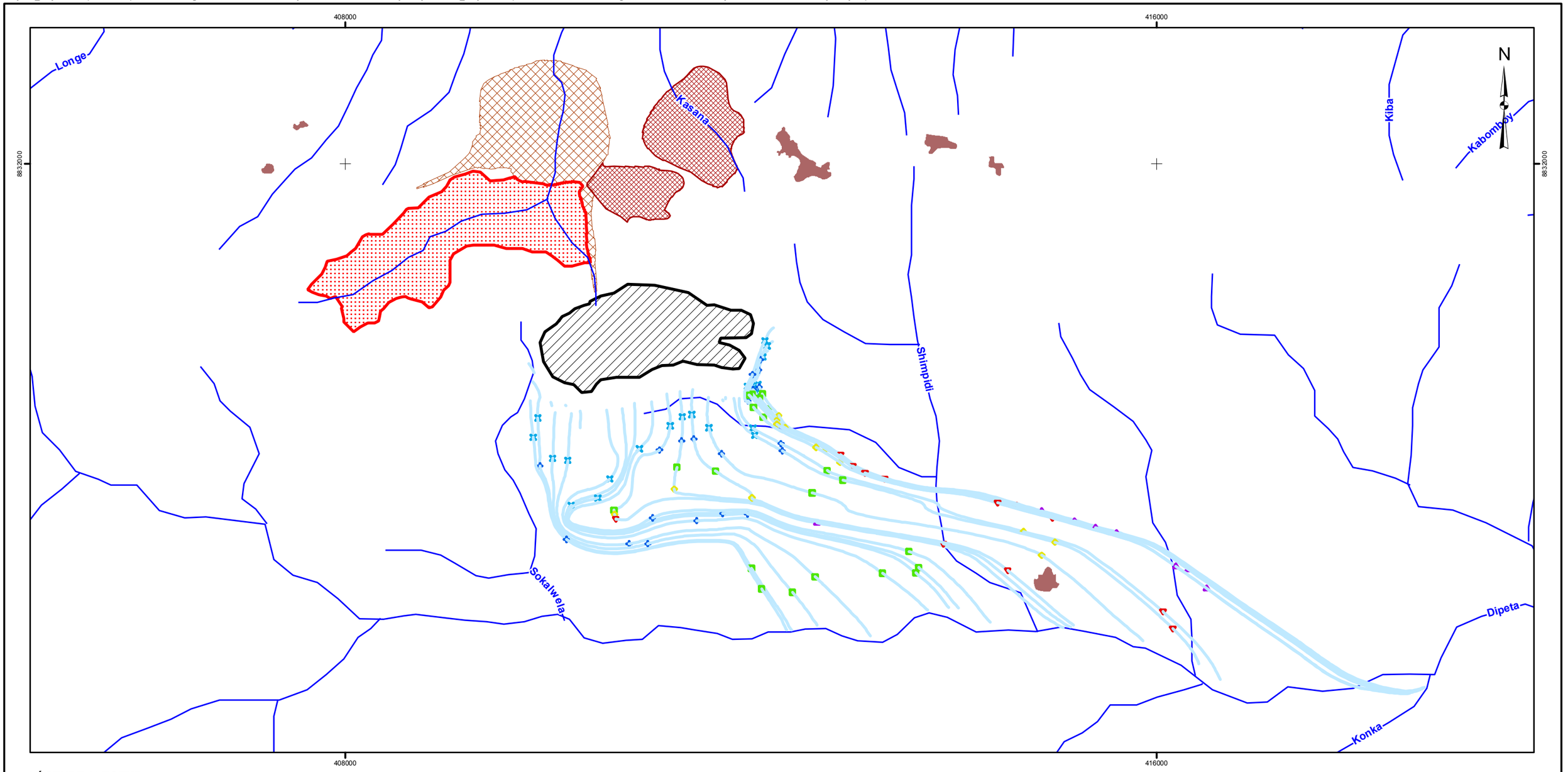
RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	**FIGURE: 39**	
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Particle traces Steady state Scenario 1 Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Particle traces Steady state Scenario 1 Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PARTICLE TRACE

TIME

- 360 days
- 720 days
- 1440 days
- 2880 days
- 4320 days
- 5760 days
- Flow path

0.6 0 0.6 1.2 1.8 2.4 3

ÉCHELLE 1:38,000 KILOMÈTRES
SCALE 1:38,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

STEADY STATE PARTICLE TRACES FROM THE KWATEBALA PIT AT POST CLOSURE (SCENARIO 1) SENSITIVITY ANALYSIS

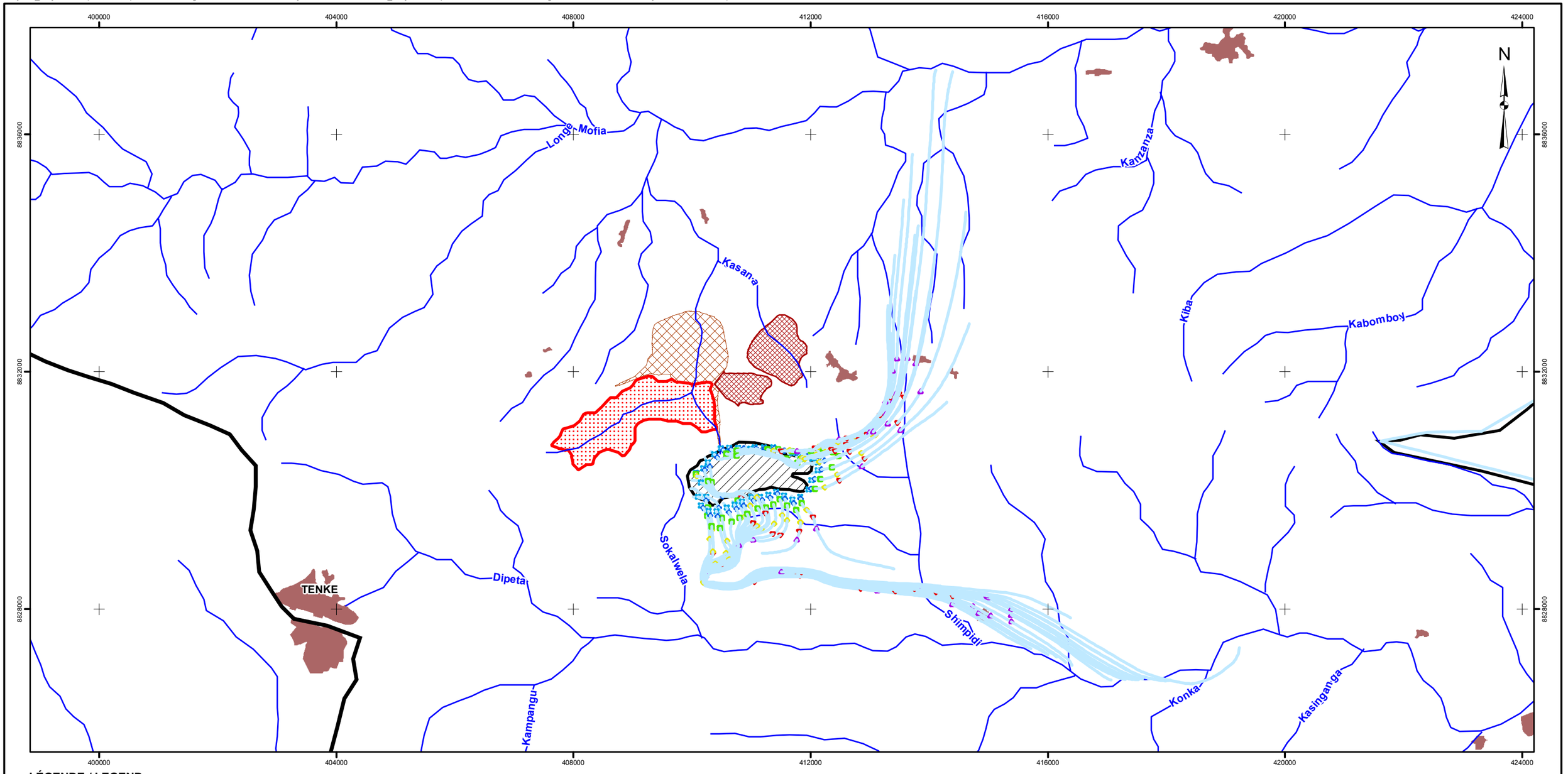
Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	**FIGURE: 39a**
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Particle traces Steady state Scenario 2.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Particle traces Steady state Scenario 2A.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PARTICLE TRACE

TIME

- 360 days
- 720 days
- 1440 days
- 2880 days
- 4320 days
- 5760 days
- Flow path

1 0 1 2 3 4 5

ÉCHELLE 1:65,000 KILOMÈTRES
SCALE 1:65,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

STEADY STATE PARTICLE TRACES FROM THE KWATEBALA PIT AT POST CLOSURE (SCENARIO 2)

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

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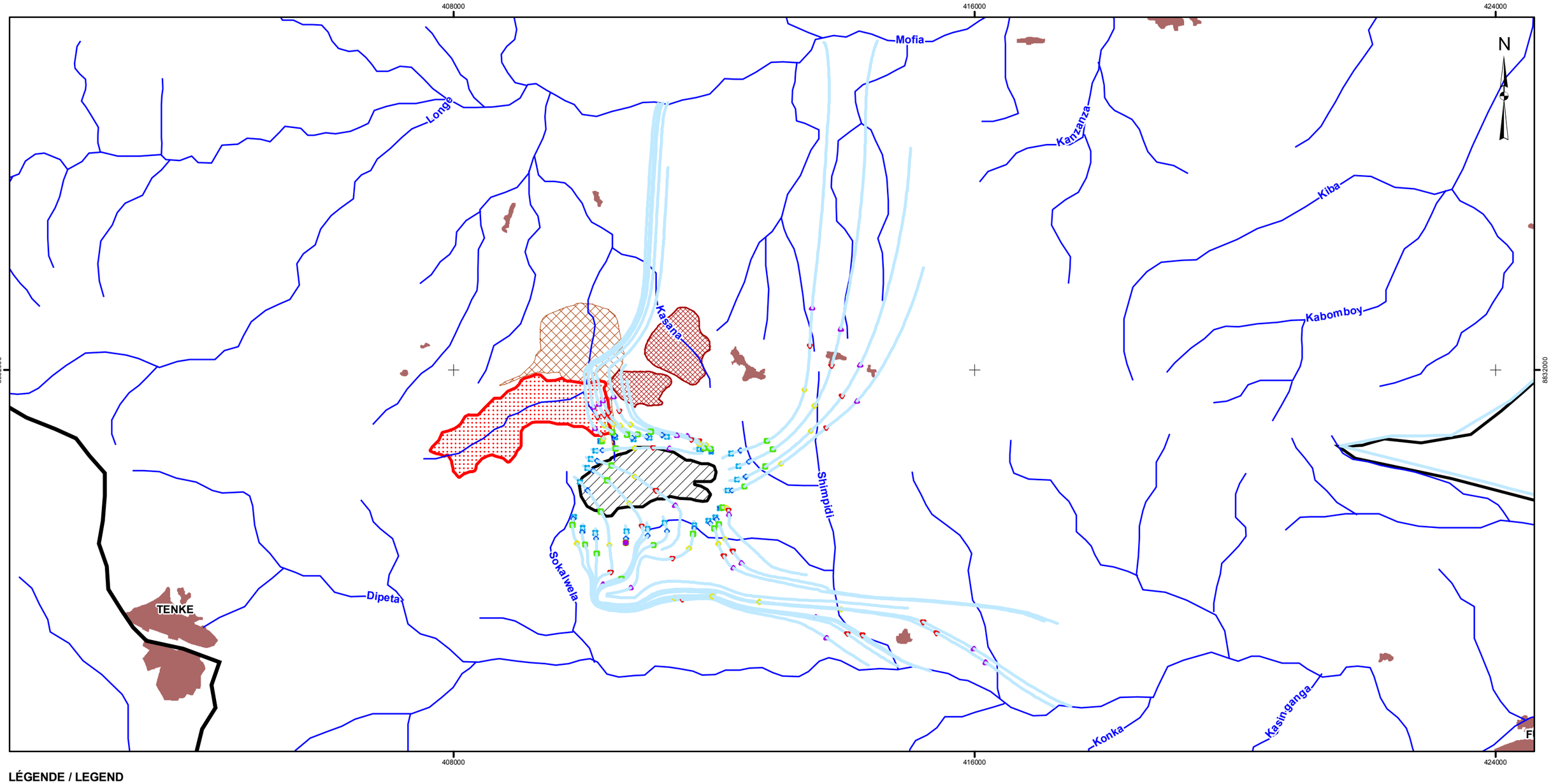
N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	**FIGURE: 40**
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Particle traces Steady state Scenario 2A Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Particle traces Steady state Scenario 2A Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

PARTICLE TRACE TIME

- 360 days
- 720 days
- 1440 days
- 2880 days
- 4320 days
- 5760 days
- Flow path

1 0 1 2 3 4

ÉCHELLE 1:60,000 KILOMÈTRES
SCALE 1:60,000 KILOMETRES

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TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE
STEADY STATE PARTICLE TRACES FROM THE KWATEBALA PIT AT POST CLOSURE (SCENARIO 2) SENSITIVITY ANALYSIS

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N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	**FIGURE: 40a**	
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Scenario 1: Figure 39 (Scenario 1) shows that groundwater flow from the pit will be in a southerly direction towards the Dipeta River. Locally, groundwater flow will be controlled by the west to east striking hydraulic conductivity contrast between the different geological lithologies present to the south of the pit. Under steady-state conditions, groundwater from the pit could reach the Dipeta River in about 12 to 16 years.

Scenario 2: Figure 40 (Scenario 2) shows that groundwater flow from the pit will be towards the north and northeast (towards the Mofia River) and to the south towards the Dipeta River where the west to east striking hydraulic conductivity contrast between the different geological lithologies present to the south of the pit will locally control the flow pattern. Groundwater from the pit could reach the Dipeta River in about 12 to 16 years. Under steady-state conditions, groundwater flow from the pit could reach the Mofia River in about 32 years.

Post Closure Affected Area Under Steady State Conditions

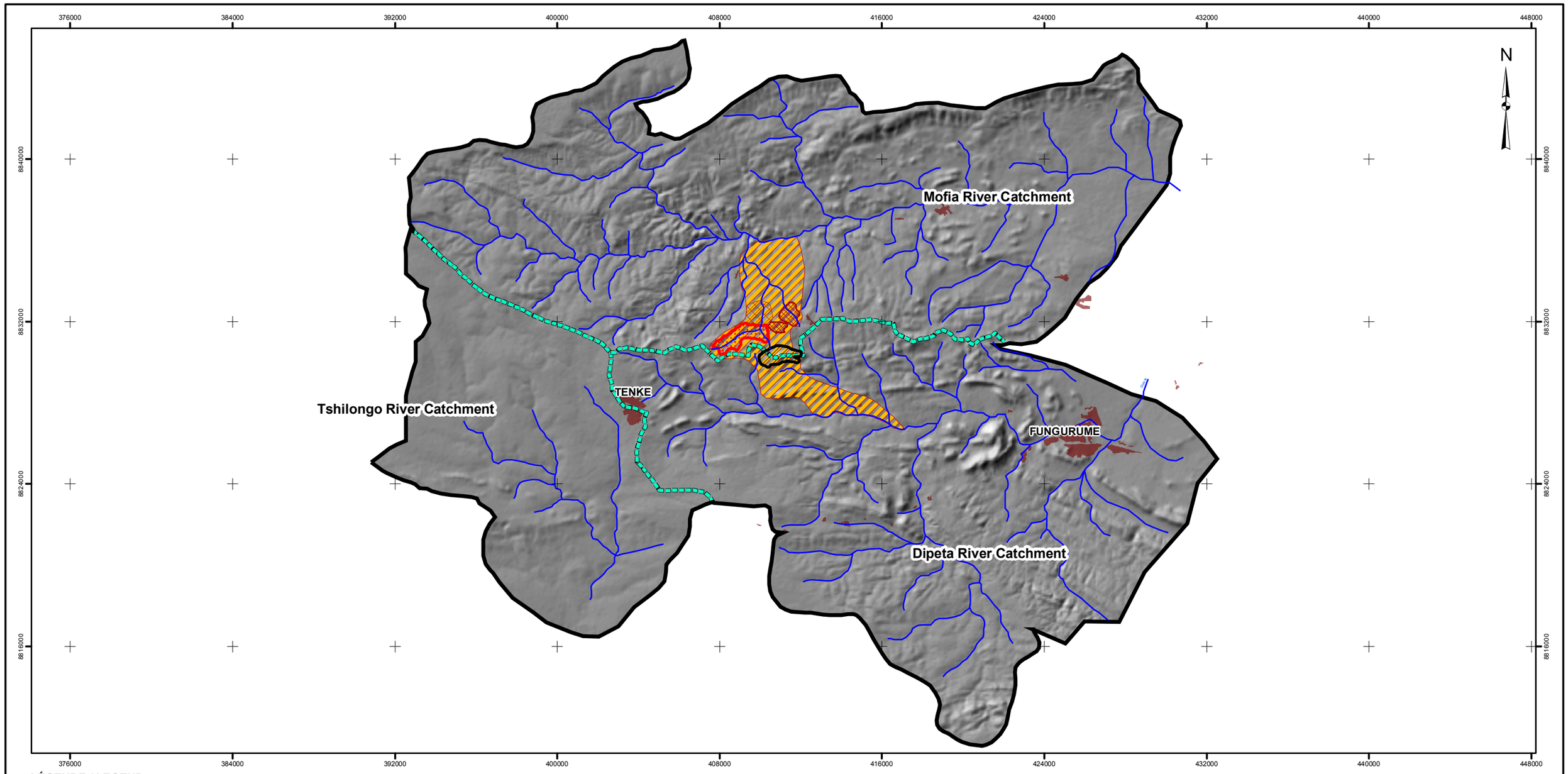
Figures 41, 41a, 42 and 42a show the area that could be affected by seepage from the pit lake, tailings dam, and waste rock facilities under the post-closure steady state simulation for Scenarios 1 and 2. Under both scenarios, there would be long-term groundwater discharge from mine facilities to the Mofia and Dipeta Rivers.

8.4.2.2 Post-Closure Steady-State Sensitivity Analysis

The post-closure steady state conditions under the assumption of a modified dewatering plan were similar to those for the base case plan. The results are as follows:

Pit Lake

A pit lake will form in the open pit at post-closure as groundwater enters the pit and groundwater levels recover from the effects of dewatering. The modeling indicates that the pit will ultimately be a "through-flow" pit with groundwater entering the pit on the up-gradient side and exiting on the down-gradient side and flowing toward the Dipeta and Mofia rivers and their tributaries. The time for the pit lake to begin discharging to groundwater (through-flow) ranges from about 12 years after closure under Scenario 1 to about 40 years under Scenario 2. Quasi-steady state conditions for the pit lake would be reached after about 40 years for Scenario 1 and after approximately 160 years for Scenario 2.



LÉGENDE / LEGEND

- CAPTURE ZONE
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- MODELLED AREA
- CATCHMENT DIVIDE
- RIVER

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
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TITRE
TITLE **AREA AFFECTED BY SEEPAGE FROM THE MINE PIT, TAILINGS STORAGE FACILITY, WASTE ROCK FACILITIES AND STOCKPILES AT STEADY STATE POST CLOSURE (SCENARIO 1)**

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N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
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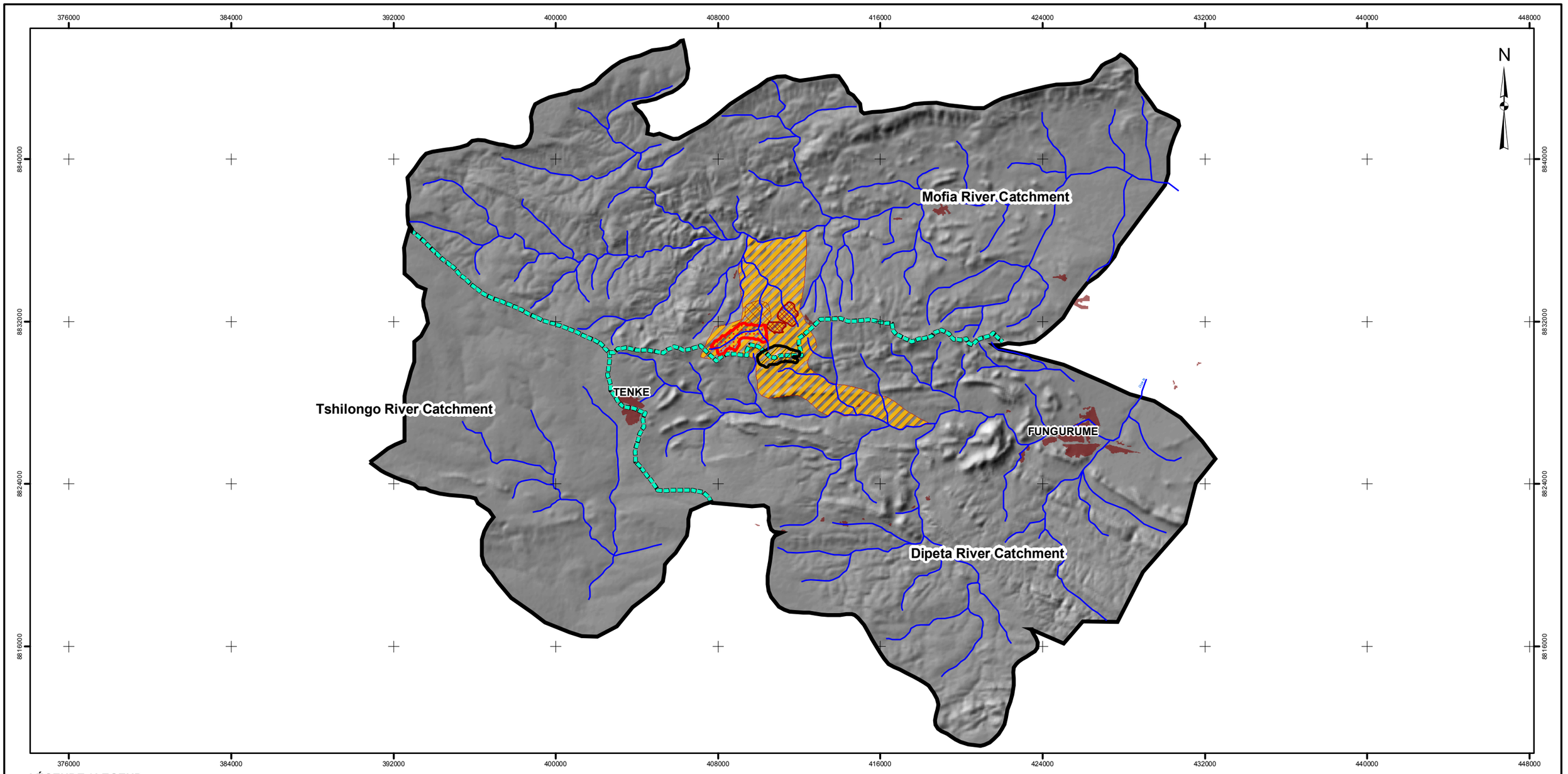
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 41

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Areas affected by seepage - steady state post closure Scenario 1 Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Areas affected by seepage - steady state post closure Scenario 1 Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- CAPTURE ZONE
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
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- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- MODELLED AREA
- CATCHMENT DIVIDE
- RIVER

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

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TITRE
TITLE **AREA AFFECTED BY SEEPAGE FROM THE MINE PIT, TAILINGS STORAGE FACILITY, WASTE ROCK FACILITIES AND STOCKPILES AT STEADY STATE POST CLOSURE (SCENARIO 1) SENSITIVITY ANALYSIS**

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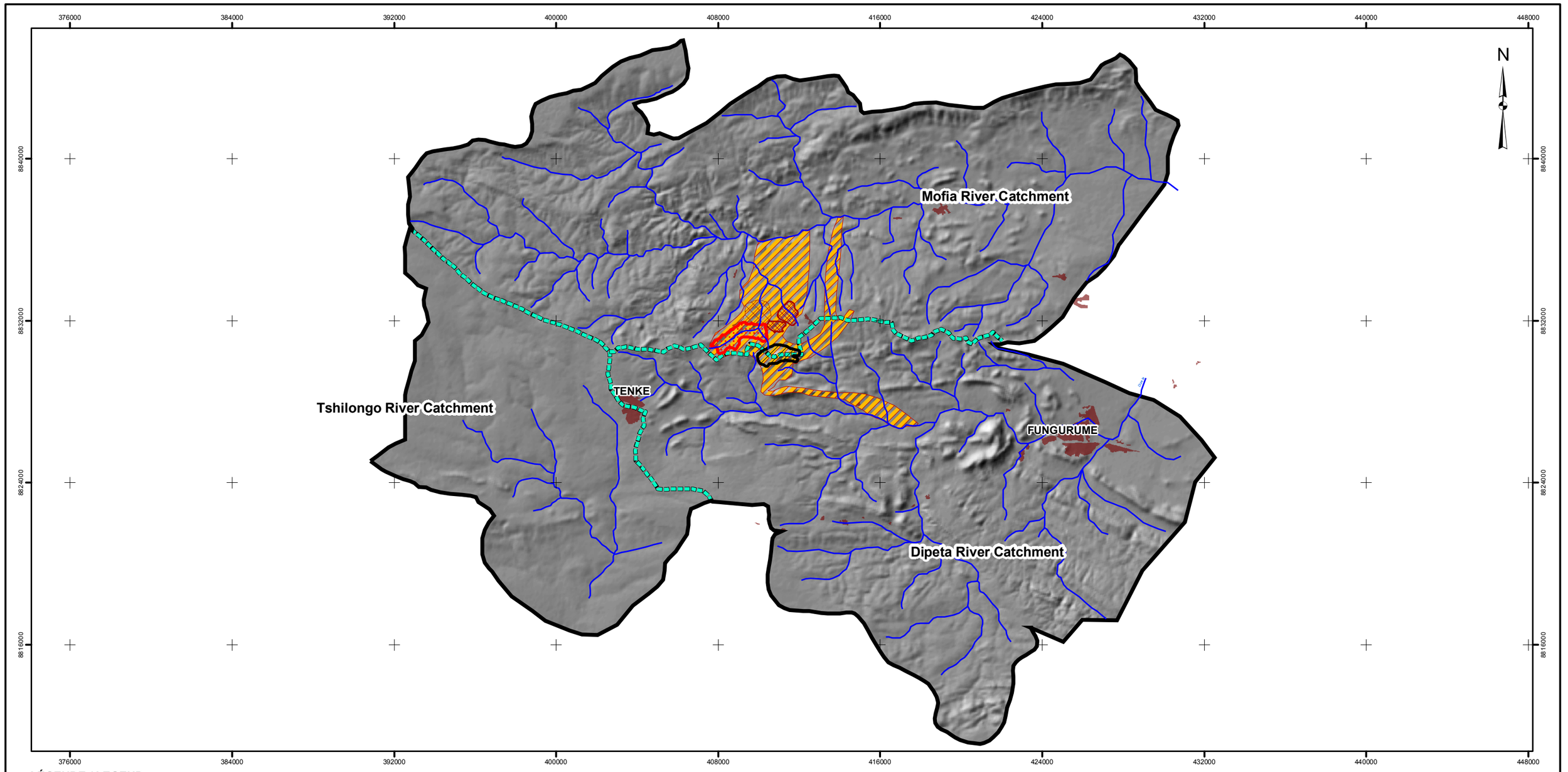
N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 41a

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Areas affected by seepage - steady state post closure Scenario 2.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Areas affected by seepage - steady state post closure Scenario 2.pdf



LÉGENDE / LEGEND

- CAPTURE ZONE
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- ÉTABLISSEMENT HUMAIN / SETTLEMENT
- MODELLED AREA
- CATCHMENT DIVIDE
- RIVER

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
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TENKE FUNGURUME MINING SARL

TITRE
TITLE **AREA AFFECTED BY SEEPAGE FROM THE MINE PIT, TAILINGS STORAGE FACILITY, WASTE ROCK FACILITIES AND STOCKPILES AT STEADY STATE POST CLOSURE (SCENARIO 2)**

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

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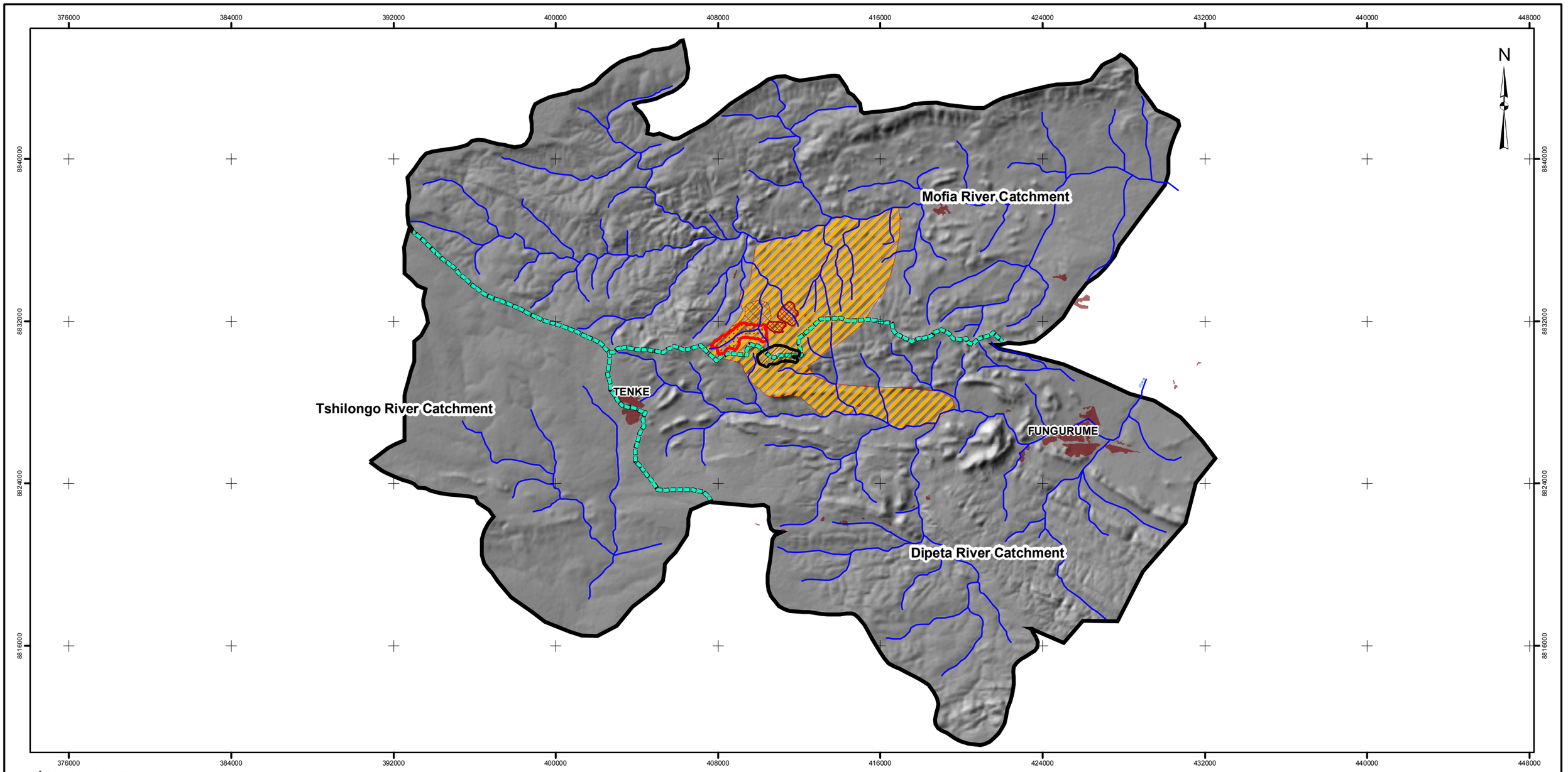
DESSIN / DESIGN	HvR	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 42

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Areas affected by seepage - steady state post closure Scenario 2 Sensitivity Analysis.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Areas affected by seepage - steady state post closure Scenario 2 Sensitivity Analysis.pdf



LÉGENDE / LEGEND

- CAPTURE ZONE
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
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- MODELLED AREA
- CATCHMENT DIVIDE
- RIVER

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

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TENKE FUNGURUME MINING SARL

TITRE / TITLE

AREA AFFECTED BY SEEPAGE FROM THE MINE PIT, TAILINGS STORAGE FACILITY, WASTE ROCK FACILITIES AND STOCKPILES AT STEADY STATE POST CLOSURE (SCENARIO 2) SENSITIVITY ANALYSIS

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

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DESSIN / DESIGN	HvR	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 42a

Analysis includes a water balance for the pit lake and estimated seepage pathways from the pit lake at post-closure steady-state conditions.

Pit Lake Water Balance

Results for Scenario 1 and 2 are as follows:

Scenario 1:

The total groundwater outflow from the Kwatebala Pit = 10,500 cubic meters per day.

This outflow is made up as follows:

1. Lateral groundwater throughflow from upstream catchment areas = 7,300 cubic meters per day.
2. Recharge of 40 percent of precipitation across the pit footprint = 3,200 cubic meters per day.

Scenario 2:

The total groundwater outflow from the Kwatebala Pit = 3,700 cubic meters per day.

This outflow is made up as follows:

1. Lateral groundwater throughflow from upstream catchment areas = 500 cubic meters per day.
2. Recharge of 40 percent of precipitation across pit footprint = 3,200 cubic meters per day.

Seepage Pathways from Pit Lake

Particle tracking was used to determine the pathways of seepage from the pit lake post-closure (Figures 39a and 40a). The horizontal distance traveled using the steady state simulated groundwater flow field is also indicated on the particle trace figures. An effective porosity of one percent has been used as representing the worst case in terms of travel distance of a potential contaminant. As an illustration the distance between the symbol markings on the particle traces of Figures 39a and 40a show the horizontal distance traveled in 1, 2, 4, 8, 12 and 16 years after steady state flow conditions have been established.

Scenario 1: Figure 39a (Scenario 1) shows that groundwater flow from the pit will be in a southerly direction towards the Dipeta River. Locally, groundwater

flow will be controlled by the west to east striking hydraulic conductivity contrast between the different geological lithologies present to the south of the pit. Under steady-state conditions, groundwater from the pit could reach the Dipeta River in about 12 to 16 years.

Scenario 2: Figure 40a (Scenario 2) shows that groundwater flow from the pit will be towards the north and northeast (towards the Mofia River) and to the south towards the Dipeta River where the west to east striking hydraulic conductivity contrast between the different geological lithologies present to the south of the pit will locally control the flow pattern. Groundwater from the pit could reach the Dipeta River in about 12 to 16 years. Under steady-state conditions, groundwater flow from the pit could reach the Mofia River in about 32 years.

Post Closure Affected Area Under Steady State Conditions

Figures 41a and 42a show the area that could be affected by seepage from the pit lake, tailings dam, and waste rock facilities under the post-closure steady state simulation for Scenarios 1 and 2. Under both scenarios, there would be long-term groundwater discharge from mine facilities to the Mofia and Dipeta Rivers.

8.5 IMPACT OF MINE DEWATERING AND CLOSURE ON BASEFLOW AND SPRINGS

8.5.1 Baseflow

An estimate of the river baseflow originating from groundwater discharge was provided in Section 7.7.

8.5.1.1 Baseflow Quantity

The steady state water balance is made up as follows:

1. Model Inflows – Groundwater recharge = 603,772 cubic meters per day.
2. Model Outflows – Dipeta catchment = 244,038 cubic meters per day.
3. Model Outflows – Mofia catchment = 269,970 cubic meters per day.
4. Model Outflows – Tshilongo sub-catchment = 89,764 cubic meters per day.

Figures 43 and 44 shows the simulated baseflow for the Mofia and Dipeta rivers and part of the sub-catchment of the Tshilongo River for Scenario 1 and Scenario 2, respectively. The figures show that mine dewatering will have the greatest impact on the baseflow of the Dipeta River with little if any impact on the Mofia. Without mitigation, baseflow in the Dipeta River will decrease from about 240,000 cubic meters per day pre-mining to 200,000 cubic meters per day post mining – a decrease of 40,000 cubic meters per day (about 460 liters per second). However, the discharge of excess mine dewatering water will largely offset this impact. The reduction in baseflow on the Dipeta River will be significantly less for Scenario 2 (Figure 44) in the range of about 8,000 cubic meters per day (about 90 liters per second). Dewatering impacts on the Mofia and Tshilongo rivers will be minimal (less than 5,000 cubic meters per day (60 liters per second).

Figure 44a show the simulated impacts to baseflow under the assumption of a modified dewatering plan for both scenarios. Figure 44a shows that, with no mitigation, there could be a decrease in baseflow of about 40,000 cubic meters per day in the Dipeta River (similar to the base case conditions). The figure shows that with no mitigation, there could be a decrease in baseflow of about 2,500 cubic meters per day on the Mofia River and up to 5,000 cubic meters per day on the Dipeta. These changes are similar to the base case condition. There will be little, if any, impact on the Tshilongo River.

8.5.1.2 Baseflow Supported Vegetation

The baseline groundwater assessment included information on the presence of groundwater-supported vegetation along stream channels. The gallery forest vegetation is found in the valley bottom of some of the tributary streams near the Kwatebala open pit and is sustained in the dry season by shallow groundwater. An issue identified in the scoping of the TFM project was whether mine dewatering would adversely affect this vegetation by lowering groundwater levels in the vegetated areas.

The location of the gallery forest is shown on Figure C2.10-2 of the baseline report and in Figure 9. Gallery forest is found in isolated pockets of in the headwaters of the Mofia, Kasana, Kimungu and Kalengimiawa rivers. The groundwater model was used to determine the changes in groundwater levels that could occur at the gallery forest locations. The results are summarized in Table 9 and Table 10 for Scenarios 1 and 2, respectively, for approximately 24 locations where gallery forest has been identified. Tables 9a and 10a represent the respective sensitivity figures for the same locations.

Figure 43 Simulated River Baseflow for Scenario 1 (No Mitigation)

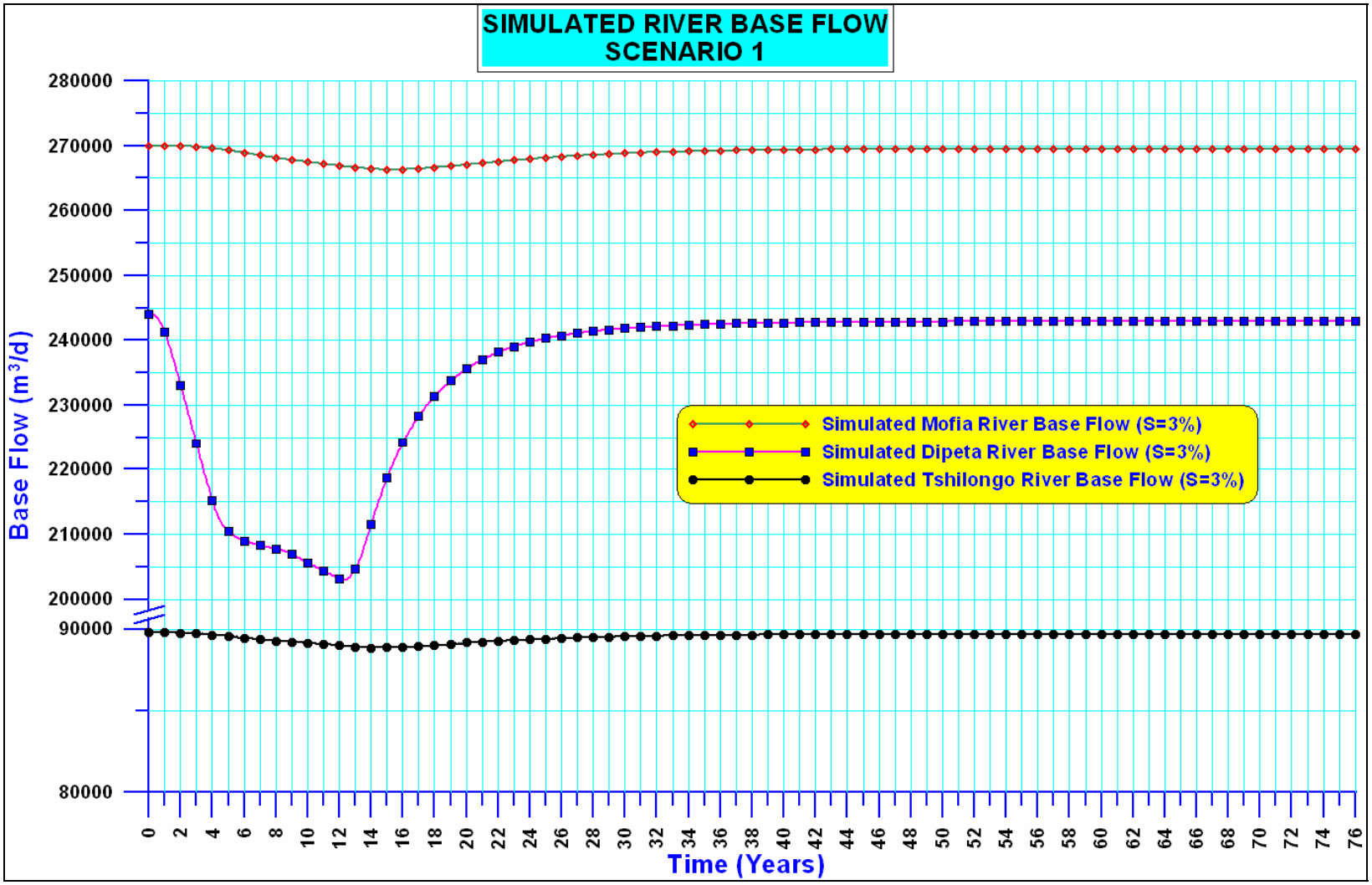


Figure 44 Simulated River Baseflow for Scenario 2 (No Mitigation)

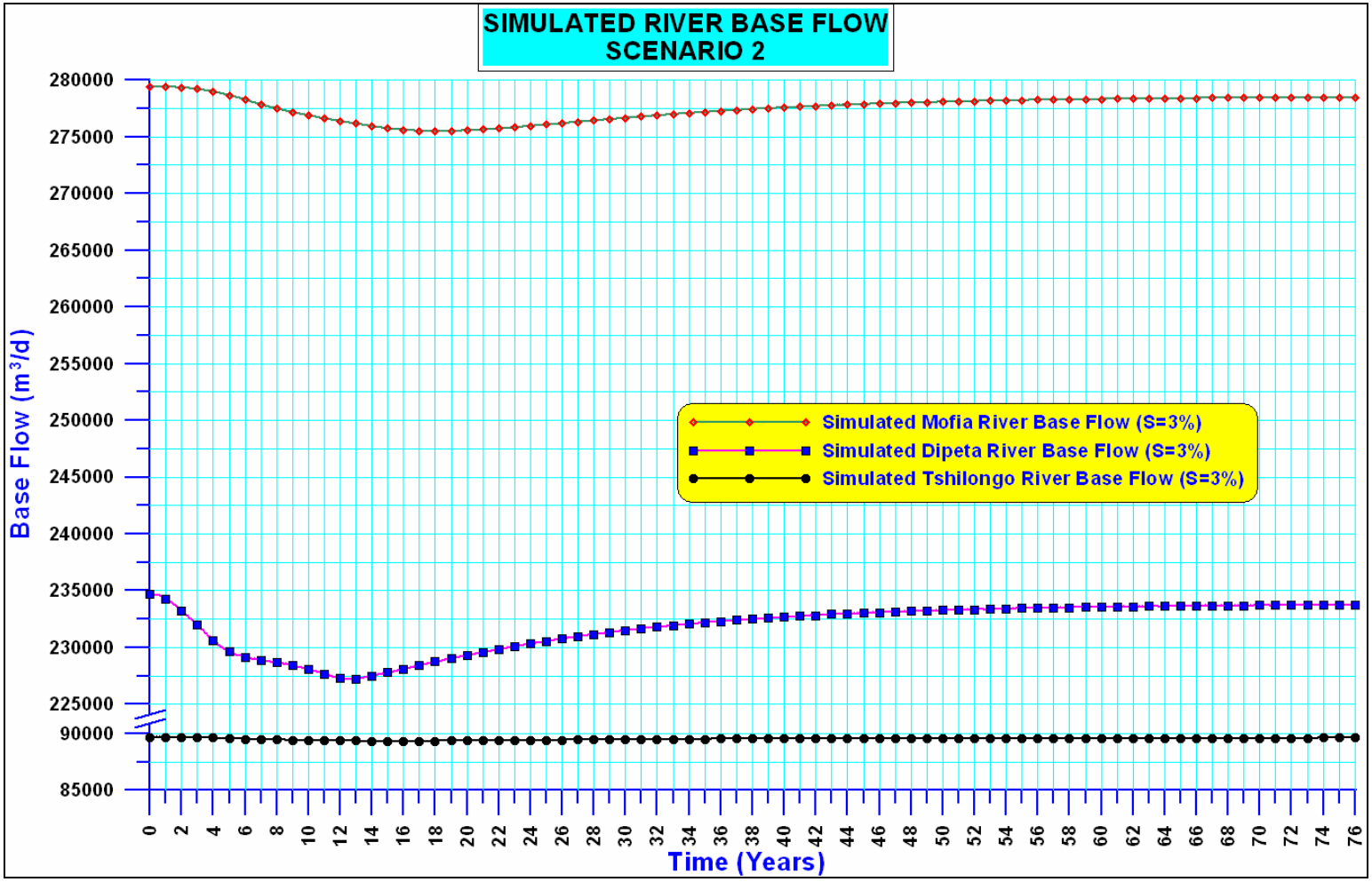
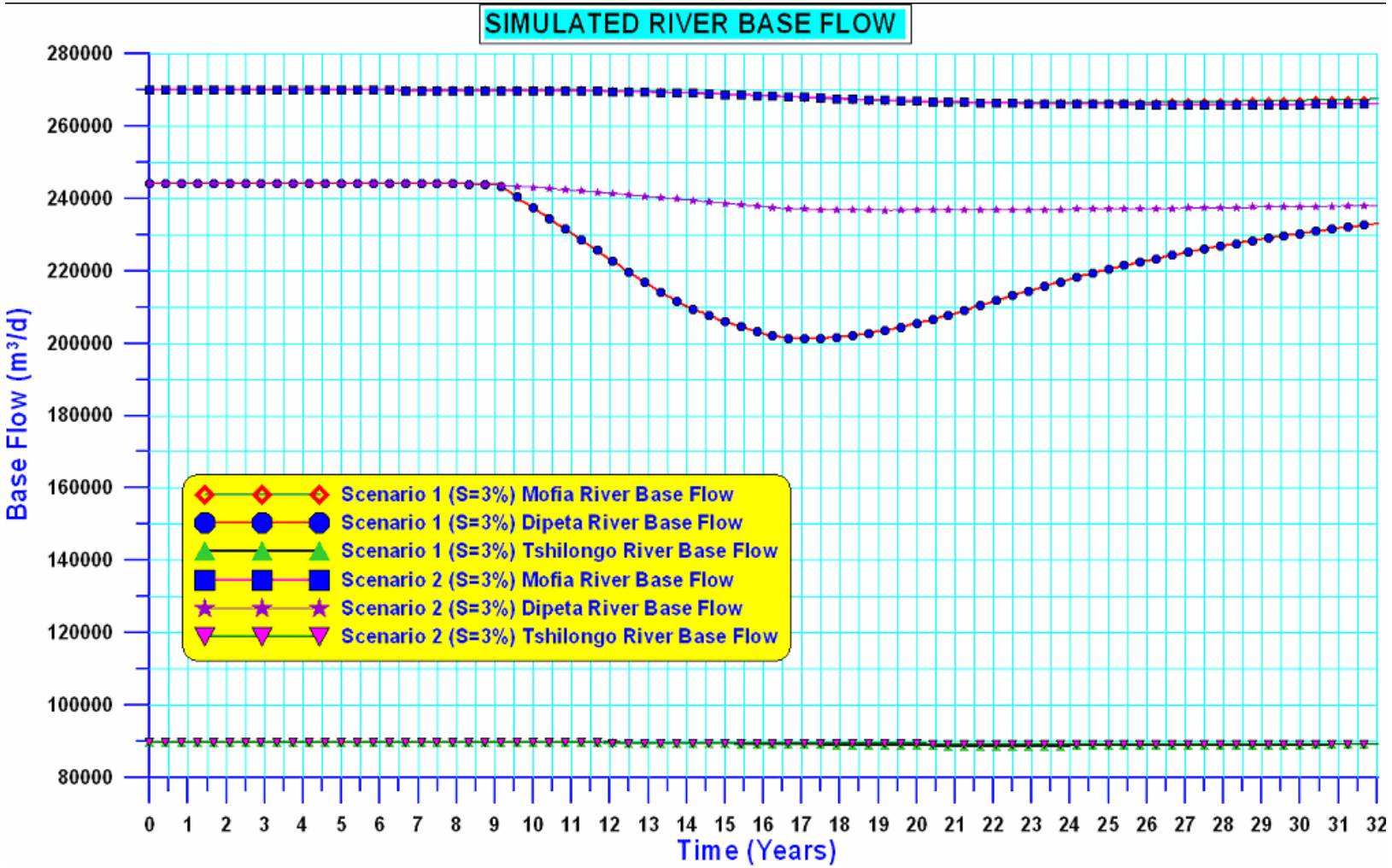


Figure 44a Simulated River Base Flow for Scenario 1 and Scenario 2 (No Mitigation) – Sensitivity Analysis



Drawdown impacts at the gallery forest locations, assuming a modified dewatering plan, are similar to or slightly smaller than those under the base case conditions.

Table 9 Predicted Drawdown at Gallery Forest Locations (Scenario 1)

Gallery Forest ID – See Figure 9	Drawdown Impact* after 1 year (m)	Drawdown Impact* after 2 years (m)	Drawdown Impact* after 4 years (m)	Drawdown Impact* after 8 years (m)	Drawdown Impact* after 12 years (m)	Drawdown Impact* at steady state post closure (m)
1	0.26	1.64	7.34	17.40	22.62	2.66
2	0.02	0.29	2.23	8.36	11.66	1.53
3	0.00	0.04	0.65	3.86	6.37	0.89
4	0.00	0.04	0.65	3.75	5.93	0.83
5	0.00	0.01	0.25	1.95	3.63	0.51
6	0.00	0.00	0.01	0.17	0.14	0.05
7	0.01	0.18	1.75	7.06	10.46	0.86
8	0.02	0.39	2.64	7.02	9.19	0.28
9	0.03	0.40	2.41	6.03	7.89	0.21
10	0.05	0.51	2.54	5.47	7.05	0.15
11	0.12	0.67	2.23	3.32	4.36	0.04
12	0.24	1.19	3.75	5.34	7.00	0.06
13	0.27	1.31	4.09	5.77	7.57	0.06
14	0.00	0.00	0.01	0.23	0.65	0.10
15	0.00	0.00	0.02	0.39	1.02	0.15
16	0.00	0.00	0.02	0.41	1.11	0.16
17	0.00	0.00	0.00	0.18	0.55	0.08
18	0.00	0.00	0.00	0.00	0.02	0.00
19	0.00	0.00	0.00	0.00	0.03	0.00
20	0.00	0.01	0.01	0.13	0.35	0.03
21	0.00	0.00	0.02	0.07	0.09	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.03	0.06	0.00
24	0.00	0.00	0.17	1.63	3.18	0.44

* Positive values indicative of water level below pre-mining steady state water level. Negative values indicative of water level above pre-mining steady state water level.

Table 9a Predicted Drawdown at Gallery Forest Locations (Scenario 1) – Sensitivity Analysis

Gallery Forest ID – See Figure 9	Drawdown Impact* after 1 year (m)	Drawdown Impact* after 2 years (m)	Drawdown Impact* after 5 years (m)	Drawdown Impact* after 8 years (m)	Drawdown Impact* after 16 years (m)	Drawdown Impact* at steady state post closure (m)
1	0.28	0.97	2.89	4.11	20.81	2.12
2	0.03	0.22	1.18	1.93	9.08	1.28
3	0.00	0.05	0.58	1.20	4.73	0.70
4	0.00	0.04	0.50	1.00	4.23	0.68
5	0.00	0.03	0.35	0.79	2.79	0.38
6	0.00	0.00	0.03	0.08	0.28	0.04
7	0.04	0.22	1.20	2.10	9.29	0.42
8	0.06	0.23	0.77	1.13	8.50	-0.20
9	0.06	0.22	0.65	0.94	7.39	-0.20
10	0.09	0.25	0.60	0.81	6.94	-0.21
11	0.15	0.26	0.39	0.45	5.08	-0.13
12	0.26	0.43	0.63	0.71	8.25	-0.22
13	0.29	0.47	0.68	0.77	8.95	-0.23
14	0.00	0.00	0.03	0.11	0.46	0.06
15	0.00	0.00	0.06	0.18	0.73	0.09
16	0.00	0.00	0.06	0.19	0.78	0.09
17	0.00	0.00	0.03	0.09	0.39	0.05
18	0.00	0.00	0.00	0.00	0.02	0.00
19	0.00	0.00	0.00	0.00	0.02	0.00
20	0.01	0.01	0.02	0.04	0.20	0.01
21	0.00	0.00	0.01	0.01	0.09	-0.00
22	0.00	0.00	0.00	0.00	0.01	-0.00
23	0.00	0.00	0.00	0.01	0.04	0.01
24	0.00	0.01	0.14	0.33	1.65	0.42

* Positive values indicative of water level below pre-mining steady state water level. Negative values indicative of water level above pre-mining steady state water level.

Table 10 Predicted Drawdown at Gallery Forest Locations (Scenario 2)

Gallery Forest ID – See Figure 9	Drawdown Impact* after 1 year (m)	Drawdown Impact* after 2 years (m)	Drawdown Impact* after 4 years (m)	Drawdown Impact* after 8 years (m)	Drawdown Impact* after 12 years (m)	Drawdown Impact* at steady state post closure (m)
1	0.17	0.73	2.65	7.06	9.41	2.65
2	0.03	0.22	1.04	3.39	4.75	1.38
3	0.01	0.10	0.65	2.54	3.75	0.97
4	0.01	0.09	0.54	2.05	2.98	0.83
5	0.00	0.05	0.51	2.26	3.45	0.76
6	0.00	0.03	0.40	1.88	2.93	0.59
7	0.11	0.77	3.48	8.52	11.43	1.34
8	0.01	0.16	1.06	3.49	4.98	0.44
9	0.01	0.14	0.94	3.16	4.55	0.41
10	0.01	0.14	0.91	3.01	4.32	0.39
11	0.02	0.10	0.32	0.53	0.66	0.04
12	0.04	0.17	0.55	0.86	1.06	0.07
13	0.04	0.19	0.60	0.93	1.15	0.08
14	0.00	0.00	0.11	0.74	1.36	0.24
15	0.00	0.01	0.18	1.08	1.88	0.33
16	0.00	0.01	0.18	1.12	1.94	0.34
17	0.00	0.00	0.09	0.61	1.14	0.20
18	0.00	0.00	0.00	0.08	0.20	0.04
19	0.00	0.00	0.00	0.05	0.12	0.02
20	0.00	0.00	0.03	0.37	0.81	0.15
21	0.00	0.00	0.00	0.01	0.02	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.01	0.02	0.00
24	0.00	0.00	0.08	0.75	1.58	0.67

* Positive values indicative of water level below pre-mining steady state water level. Negative values indicative of water level above pre-mining steady state water level.

Table 10a Predicted Drawdown at Gallery Forest Locations (Scenario 2) – Sensitivity Analysis

Gallery Forest ID	Drawdown Impact* after 1 year (m)	Drawdown Impact* after 2 years (m)	Drawdown Impact* after 5 years (m)	Drawdown Impact* after 8 years (m)	Drawdown Impact* after 16 years (m)	Drawdown Impact* at steady state post closure (m)
1	0.10	0.32	0.84	1.06	6.29	0.96
2	0.02	0.11	0.39	0.53	2.94	0.50
3	0.00	0.04	0.18	0.28	2.24	0.23
4	0.01	0.04	0.20	0.28	1.77	0.26
5	-0.00	-0.00	0.06	0.12	2.07	0.06
6	-0.00	-0.01	0.01	0.04	1.74	-0.02
7	-0.14	-0.29	-0.42	-0.41	9.51	-0.78
8	-0.01	-0.05	-0.15	-0.20	3.00	-0.46
9	-0.01	-0.05	-0.13	-0.18	2.70	-0.42
10	-0.01	-0.05	-0.13	-0.18	2.58	-0.40
11	-0.01	-0.01	-0.01	-0.02	0.55	-0.04
12	-0.01	-0.02	-0.02	-0.03	0.91	-0.06
13	-0.01	-0.02	-0.03	-0.03	0.99	-0.06
14	-0.00	-0.01	-0.03	-0.03	0.68	-0.07
15	-0.00	-0.01	-0.04	-0.04	1.01	-0.10
16	-0.00	-0.01	-0.04	-0.05	1.04	-0.11
17	-0.00	-0.00	-0.02	-0.03	0.57	-0.07
18	0.00	-0.00	-0.00	-0.01	0.07	-0.02
19	0.00	0.00	-0.00	-0.00	0.05	-0.01
20	0.00	-0.00	-0.02	-0.03	0.31	-0.08
21	0.00	0.00	-0.00	-0.00	0.01	-0.00
22	0.00	0.00	0.00	0.00	0.00	-0.00
23	0.00	0.00	0.00	0.00	0.01	0.00
24	0.00	0.00	0.07	0.19	0.72	0.32

* Positive values indicative of water level below pre-mining steady state water level. Negative values indicative of water level above pre-mining steady state water level.

8.5.2 Springs

The baseline groundwater assessment and the hydro-census documented the presence of springs used for water supply purposes. The potential effect on these water supply sources was determined by using the groundwater flow models to determine the drawdown in groundwater level at each spring and well. A qualitative assessment of impact was then performed as follows:

- ***Category 1*** - If the drawdown at a spring/well was predicted to be less than 0.1 meter, the spring/well was determined to not be impacted by dewatering;

- ***Category 2*** - If the drawdown at a spring/well was predicted to be between 0.1 and 1.0 meters, the spring/well was determined to be potentially impacted but exhibit little if any change in flow and remain useable;

- ***Category 3*** - If the drawdown at a spring/well was predicted to be greater than 1.0 meters but less than 3.0 meters the spring/well was determined to show reduced discharge/yield but remain useable on a seasonal basis (wet season) only;

- ***Category 4*** - If the drawdown at the spring/well was predicted to be greater than 3.0 meters, the spring/well was determined to be adversely impacted and not useable.

Tables 11 and 12 present the drawdown impacts on springs and wells in proximity to the mine at various years for the two groundwater model scenarios. For Scenario 1 sixteen springs are predicted to become unusable for water supply purposes at the end of mining. Most of the adversely impacted springs would return to near pre-mining conditions at steady-state post closure. For Scenario 2, fifteen springs are predicted to become unusable for water supply purposes at the end of mining. Similarly, at steady-state post closure most of the springs would have been reestablished with only seasonal permanent flow reductions in a few springs. It is possible that up to five springs may not be re-established post-closure.

Drawdown impacts at the spring/well locations assuming a modified dewatering plan Tables 11a and 12b are generally similar or slightly less than those under the base case conditions.

Table 11 Drawdown at Springs and Wells (Scenario 1)

Spring ID	Drawdown Impact* After 1 Year (Operational Phase) (m)	Drawdown Impact* After 2 Years (Operational Phase) (m)	Drawdown Impact* After 4 Years (Operational Phase) (m)	Drawdown Impact* After 8 Years (Operational Phase) (m)	Drawdown Impact* After 12 Years (Operational Phase) (m)	Impact Category	Drawdown Impact* at Steady State Conditions (Post Closure Phase) (m)	Impact Category
Ditoma Spring	0.45	2.12	8.60	19.43	24.36	4	3.03	4
Kalengimiawa Spring	0.07	0.59	2.57	4.91	6.26	4	0.10	2
Kamisale Spring	0.53	2.84	10.72	20.24	25.84	4	1.91	3
Kasanga 2 Spring	0.00	0.01	0.12	0.76	1.33	3	0.07	1
Kazenkenene 2 Spring	0.49	1.98	7.74	17.54	21.88	4	2.72	3
Kazenkenene Spring	0.34	1.56	6.67	16.15	20.31	4	2.55	3
Kimatuka Spring	0.00	0.08	1.01	5.17	8.47	4	0.95	2
Kimatuka Spring 2	0.00	0.00	0.13	1.17	2.39	3	0.32	2
Kimpiri Spring	0.18	1.29	6.06	14.27	19.02	4	1.52	3
Kimungu Spring	0.03	0.33	2.33	8.50	12.70	4	1.50	3
Kimungu Spring 2	0.00	0.10	1.07	5.30	8.63	4	1.06	3
Lengemiaba Spring	0.01	0.20	1.81	7.13	10.62	4	0.92	2
Longemwaba Spring	0.00	0.06	0.88	4.73	7.66	4	0.69	2
Ndela Spring	0.00	0.03	0.56	3.64	6.22	4	0.57	2
Shimpidi Spring	0.61	3.15	10.21	14.82	18.52	4	0.18	2
Sokolwala Spring	6.45	17.37	40.04	43.10	53.95	4	1.48	3
Sokolwala Spring 2	4.33	12.58	30.28	34.36	43.20	4	1.30	3
Mwela Mpande(N) Well	0.27	1.30	5.62	13.93	17.71	4	2.10	3
Kasanga 1 Spring	0.00	0.01	0.12	0.77	1.38	3	0.08	1
Dipeta River	0.02	0.13	0.41	0.60	0.97	2	0.00	1

* Positive values indicative of water level below pre-mining steady state water level. Negative values indicative of water level above pre-mining steady state water level.

Table 11a Drawdown at Springs and Wells (Scenario 1) – Sensitivity Analysis

Spring ID	Drawdown Impact* After 1 Year (Operational Phase) (m)	Drawdown Impact* After 2 Years (Operational Phase) (m)	Drawdown Impact* After 5 Years (Operational Phase) (m)	Drawdown Impact* After 8 Years (Operational Phase) (m)	Drawdown Impact* After 16 Years (Operational Phase) (m)	Impact Category	Drawdown Impact* at Steady State Conditions (Post Closure Phase) (m)	Impact Category
Ditoma Spring	0.43	1.23	3.01	3.93	21.86	4	2.61	2
Kalengimiawa Spring	0.11	0.26	0.55	0.70	6.47	4	-0.21	
Kamisale Spring	0.76	1.81	4.12	5.50	28.65	4	1.16	2
Kasanga 2 Spring	0.00	0.01	0.07	0.14	0.89	2	-0.02	
Kazenkenene 2 Spring	0.47	1.21	2.70	3.39	19.39	4	2.48	3
Kazenkenene Spring	0.33	0.99	2.46	3.19	17.67	4	2.28	3
Kimatuka Spring	0.04	0.23	1.26	2.26	7.64	4	0.62	2
Kimatuka Spring 2	0.00	0.02	0.23	0.53	1.88	3	0.23	2
Kimpiri Spring	0.40	1.13	3.13	4.49	20.11	4	0.90	2
Kimungu Spring	0.18	0.67	2.45	3.86	12.40	4	1.10	3
Kimungu Spring 2	0.04	0.24	1.31	2.33	7.71	4	0.76	2
Lengemiaba Spring	0.05	0.25	1.30	2.25	9.58	4	0.48	2
Longemwaba Spring	0.01	0.10	0.76	1.50	6.34	4	0.34	2
Ndela Spring	0.00	0.05	0.54	1.14	4.88	4	0.26	2
Shimpidi Spring	0.56	1.04	1.70	1.97	21.19	4	-0.73	
Sokolwala Spring	1.97	2.88	3.87	4.22	63.14	4	0.77	2
Sokolwala Spring 2	1.68	2.49	3.36	3.67	50.33	4	0.77	2
Mwela Mpande(N) Well	0.26	0.81	2.00	2.58	15.13	4	1.95	3
Kasanga 1 Spring	0.01	0.01	0.07	0.15	0.91	2	-0.01	
Dipeta River	0.04	0.05	0.07	0.08	2.30	3	-0.02	

Table 12 Drawdown at Springs and Wells (Scenario 2)

Spring ID	Drawdown Impact* After 1 Year (Operational Phase) (m)	Drawdown Impact* After 2 Years (Operational Phase) (m)	Drawdown Impact* After 4 Years (Operational Phase) (m)	Drawdown Impact* After 8 Years (Operational Phase) (m)	Drawdown Impact* After 12 Years (Operational Phase) (m)	Impact Category	Drawdown Impact* at Steady State Conditions (Post Closure Phase) (m)	Impact Category
Ditoma Spring	0.02	0.18	1.12	4.86	8.07	4	3.06	4
Kalengimiawa Spring	0.01	0.14	0.80	2.46	3.48	4	0.30	2
Kamisale Spring	1.48	5.29	15.21	23.61	29.06	4	2.39	3
Kasanga 2 Spring	0.00	0.00	0.09	0.75	1.42	3	0.20	2
Kazenkenene 2 Spring	0.36	1.24	3.91	9.09	11.50	4	3.56	4
Kazenkenene Spring	0.25	0.94	3.12	7.77	10.20	4	3.25	4
Kimatuka Spring	0.04	0.39	2.12	6.14	8.52	4	1.28	3
Kimatuka Spring 2	0.00	0.05	0.49	2.22	3.42	4	0.67	2
Kimpiri Spring	0.72	3.00	9.62	16.86	21.18	4	2.00	3
Kimungu Spring	0.05	0.40	2.06	6.20	8.63	4	1.73	3
Kimungu Spring 2	0.02	0.25	1.50	4.96	7.07	4	1.34	3
Lengemiaba Spring	0.13	0.83	3.68	8.79	11.73	4	1.37	3
Longemwaba Spring	0.04	0.39	2.17	6.27	8.75	4	1.12	3
Ndela Spring	0.02	0.24	1.57	5.11	7.34	4	0.99	2
Shimpidi Spring	0.13	0.71	2.76	5.81	7.54	4	0.55	2
Sokolwala Spring	13.22	28.37	58.91	61.71	75.28	4	5.37	4
Sokolwala Spring 2	11.27	25.09	53.05	56.72	68.94	4	5.10	4
Mwela Mpande(N) Well	0.13	0.58	2.18	5.91	7.85	4	2.53	3
Kasanga 1 Spring	0.00	0.00	0.10	0.77	1.47	3	0.20	2
Dipeta River	0.00	0.02	0.06	0.09	0.11	2	0.00	1

* Positive values indicative of water level below pre-mining steady state water level. Negative values indicative of water level above pre-mining steady state water level.

Table 12a Drawdown at Springs and Wells (Scenario 2) – Sensitivity Analysis

Spring ID	Drawdown Impact* After 1 Year (Operational Phase) (m)	Drawdown Impact* After 2 Years (Operational Phase) (m)	Drawdown Impact* After 5 Years (Operational Phase) (m)	Drawdown Impact* After 8 Years (Operational Phase) (m)	Drawdown Impact* After 16 Years (Operational Phase) (m)	Impact Category	Drawdown Impact* at Steady State Conditions (Post Closure Phase) (m)	Impact Category
Ditoma Spring	0.04	0.23	1.56	3.12	7.23	4	1.35	2
Kalengimiawa Spring	0.05	0.14	0.48	0.80	2.83	3	-0.31	
Kamisale Spring	0.97	2.24	5.74	8.32	33.61	4	-2.20	
Kasanga 2 Spring	0.00	0.01	0.10	0.27	1.02	3	-0.15	
Kazenkenene 2 Spring	0.46	1.33	3.67	5.19	10.86	4	1.68	2
Kazenkenene Spring	0.33	1.03	3.06	4.51	9.54	4	1.51	2
Kimatuka Spring	0.08	0.34	1.63	2.91	8.85	4	-0.35	
Kimatuka Spring 2	0.01	0.07	0.58	1.19	3.29	3	-0.04	
Kimpiri Spring	0.56	1.45	4.19	6.37	23.95	4	-1.51	
Kimungu Spring	0.16	0.59	2.28	3.78	9.38	4	0.09	1
Kimungu Spring 2	0.06	0.31	1.54	2.74	7.31	4	-0.05	
Lengemiaba Spring	0.13	0.48	2.00	3.47	12.23	4	-0.79	
Longemwaba Spring	0.05	0.25	1.33	2.52	8.72	4	-0.58	
Ndela Spring	0.03	0.16	1.03	2.06	7.11	4	-0.49	
Shimpidi Spring	0.21	0.50	1.24	1.85	6.80	4	-0.61	
Sokolwala Spring	2.49	5.02	10.59	13.84	76.80	4	-2.28	
Sokolwala Spring 2	2.34	4.71	9.94	12.98	70.22	4	-1.91	
Mwela Mpande (N) Well	0.17	0.64	2.23	3.37	7.10	4	1.21	2
Kasanga 1 Spring	0.00	0.01	0.10	0.28	1.05	2	-0.16	
Dipeta River	0.04	0.05	0.06	0.07	0.16	2	-0.01	

* Positive values indicative of water level below pre-mining steady state water level. Negative values indicative of water level above pre-mining steady state water level.

8.6 IMPACTS OF PUMPING WELLS FOR MINE WATER SUPPLY

The water supply demand is estimated to vary from 55 liters per second (wet season) to 115 liters per second (dry season peak demand). This constitutes between eight percent and 17 percent of the calculated end of mine pit inflow rates for Scenario 1 and 31 percent and 65 percent of the calculated pit inflow rate for Scenario 2, respectively.

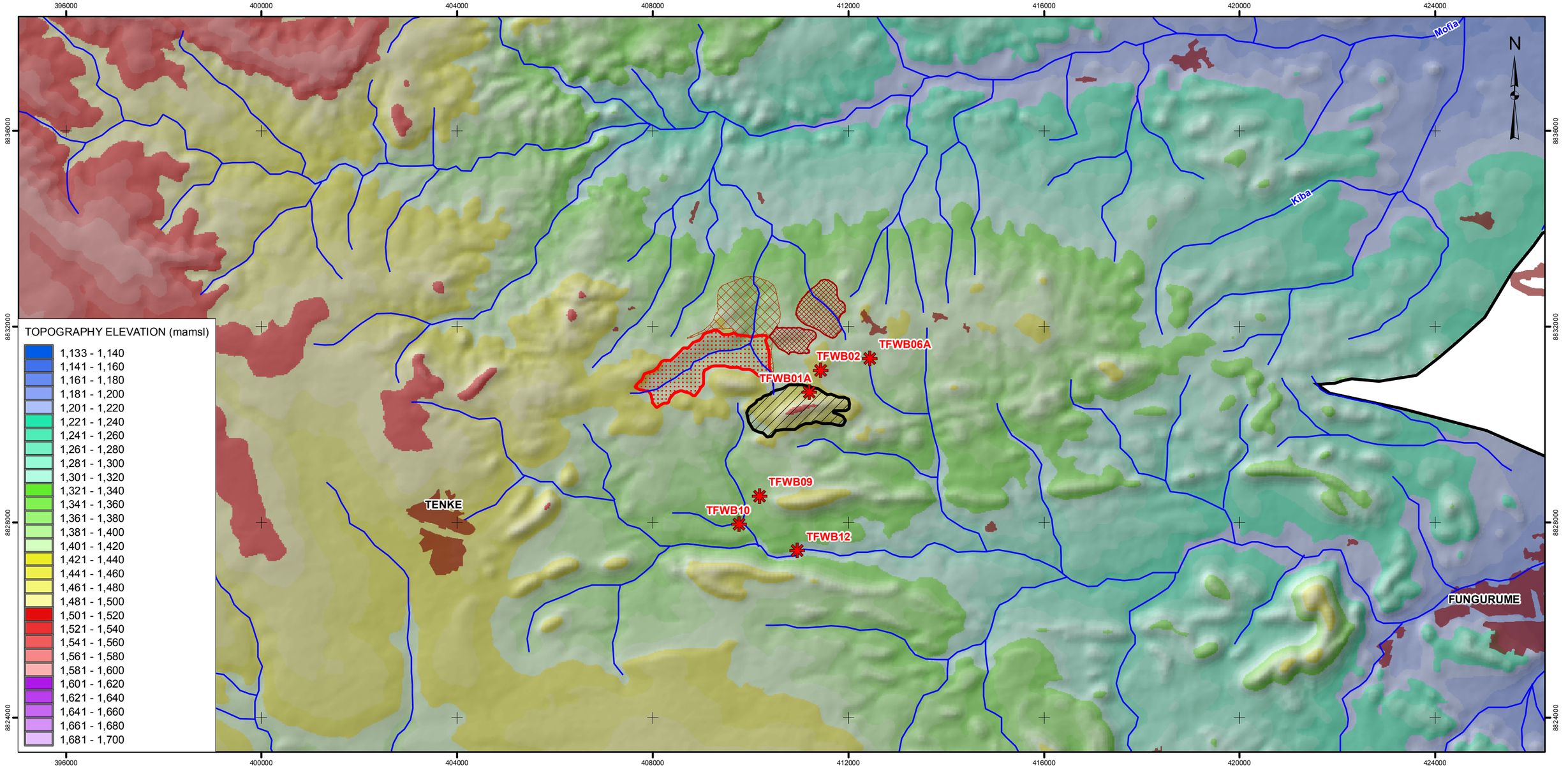
The final groundwater flow model has been used to evaluate the water supply wellfield. To provide an assessment of wellfield impacts for the ESIA, a simplified water supply wellfield layout has been incorporated into the model to provide an initial evaluation of the feasibility of supplying the required supply from groundwater. The well locations are based on the exploratory drilling work and pump testing work conducted by Golder in 2006. This assessment does not consider any possible reduction in the dewatering requirement that may result from the production wellfield and is therefore conservative in terms of impact assessment. The wellfield assessment has been conducted for both scenarios (Scenarios 1 and 2).

8.6.1 Input Parameters

The model has been run using the following wellfield input parameters:

- Dry season abstraction of 115 liters per second for six months.
- Wet season abstraction of 55 liters per second for six months.
- Six wells located as illustrated in Figure 45 at the locations of the exploratory water boreholes.
- Abstraction for mine process water from Years 0 to 9
- Pit dewatering commencing in Year 9.
- Abstraction spread evenly between the six wells.
- The average storativity of three percent has been used for both scenarios.

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Production wells used for modelling.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Production wells used for modelling.pdf



LÉGENDE / LEGEND

- PRODUCTION WELL
- RIVER
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

1 0 1 2 3 4 5 6

ÉCHELLE 1:80,000 KILOMÈTRES
SCALE 1:80,000 KILOMETRES

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE
TITLE

LOCATION OF PRODUCTION WELLS USED FOR WELLFIELD MODELLING

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	XX	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	HvR	30 Jan 2007		

FIGURE: 45

8.6.2 Discussion of Results

8.6.2.1 Scenario 1d Impact (First 8 years of mining prior to commencement of pit dewatering)

The impact of abstraction from the wellfield over the first eight years of mining is illustrated by the water level drawdown as depicted in Figure 46. This figure indicates that in general the overall drawdown surrounding the wells is less than 10 meters. The model predicts a drawdown of about 35 meters locally around borehole TFWB06A which, as noted earlier, appears to be located within a small compartment largely isolated from the main aquifer system. The area affected over the first eight years of mining by wellfield abstraction by at least one meter or more of drawdown is 68 square kilometers.

The groundwater level elevations and flow directions after eight years of mining are depicted in Figure 47. Groundwater flow directions and flow patterns are not significantly altered by the wellfield abstraction from the pre-mining steady state conditions.

8.6.2.2 Scenario 1d Impact (Final 12 years of mining – pit dewatering in operation)

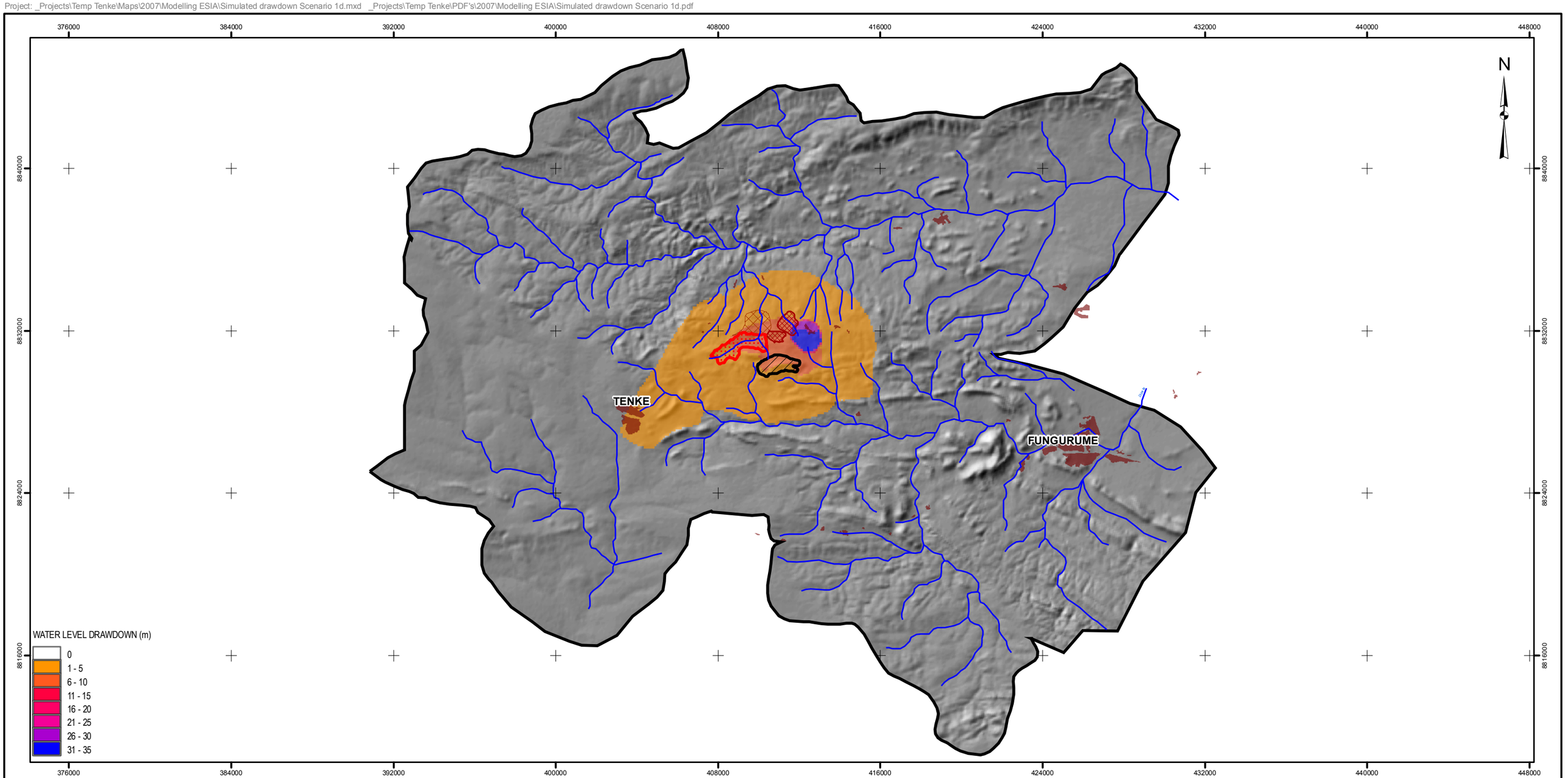
The impact of abstraction from this wellfield and the pit dewatering over the final twelve years of mining is depicted by the water level drawdown shown in Figure 48. The area affected by at least one meter or more of drawdown is 164 square kilometers. The corresponding area affected by at least one meter or more of drawdown with no wellfield abstraction (Scenario 1b, Figure 31) is marginally less at 160 square kilometers.

The simulated groundwater elevation and flow directions at the end of mining are depicted in Figure 49. The simulated groundwater flow patterns are modified in the vicinity of the Kwatebala pit where a dewatering drawdown cone has developed over time (over years 9 to 20). Comparison of Figure 49 with Figure 32 indicates that the additional abstraction from the wellfield has a minimal impact on the simulated groundwater elevations and flow directions.

8.6.2.3 Scenario 2d Impact (First 8 years of mining prior to commencement of pit dewatering)

The impact of abstraction from the wellfield over the first eight years of mining is illustrated by the groundwater level drawdown as depicted in Figure 50.

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated drawdown Scenario 1d.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated drawdown Scenario 1d.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

SCENARIO 1D
SIMULATED DRAWDOWN AFTER 8 YEARS OF WELLFIELD ABSTRACTION

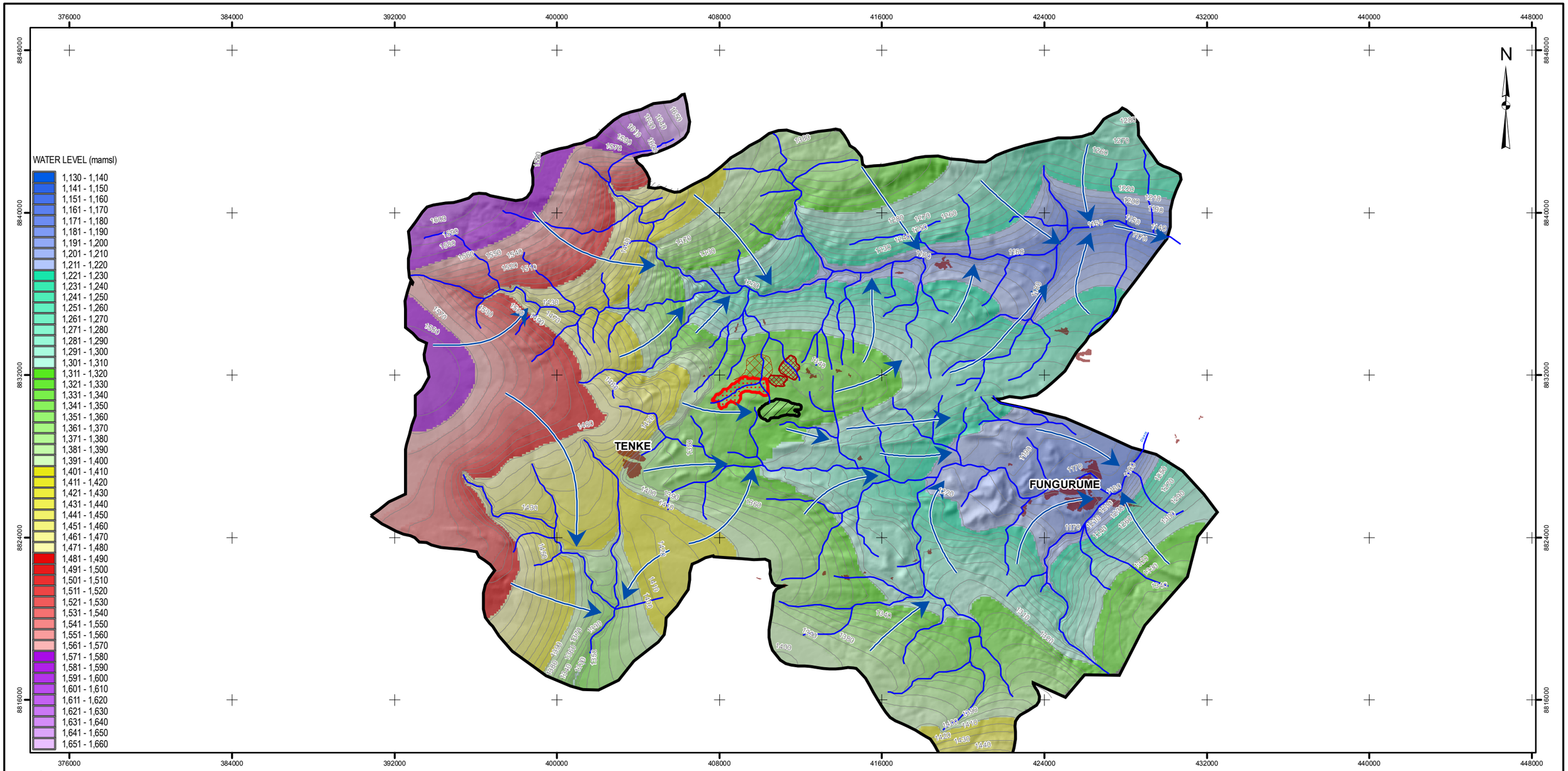
Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN — REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	**FIGURE: 46**
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated water levels Scenario 1d.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated water levels Scenario 1d.pdf



LÉGENDE / LEGEND

- GROUNDWATER FLOW DIRECTION
- RIVER
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- WATER LEVEL CONTOUR (mamsl)
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

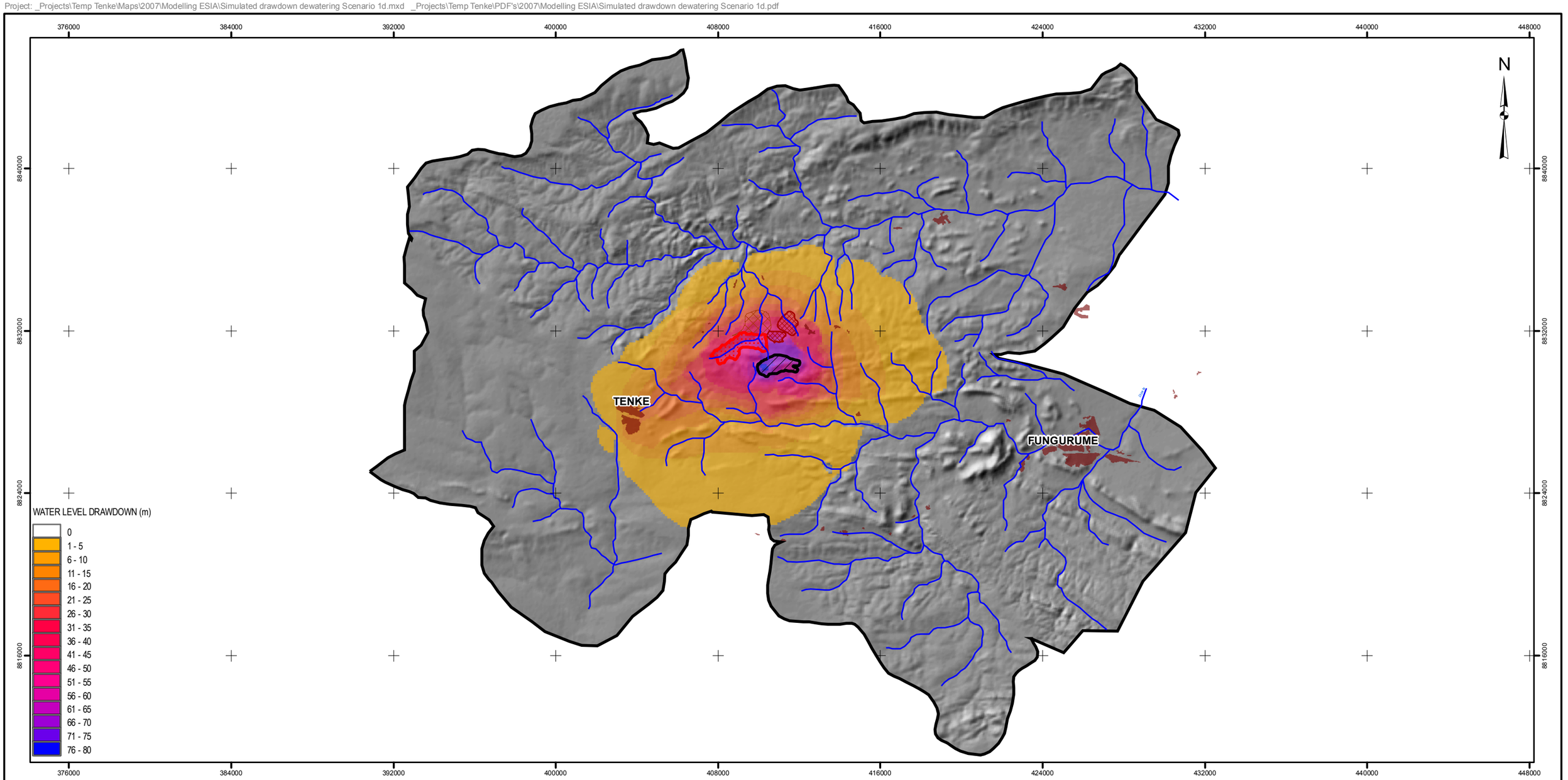
SCENARIO 1D
SIMULATED GROUNDWATER LEVELS AND FLOW DIRECTIONS AFTER 8 YEARS OF WELLFIELD ABSTRACTION

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035		ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ REVIEW	DB	30 Jan 2007	

FIGURE: 47

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated drawdown dewatering Scenario 1d.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated drawdown dewatering Scenario 1d.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

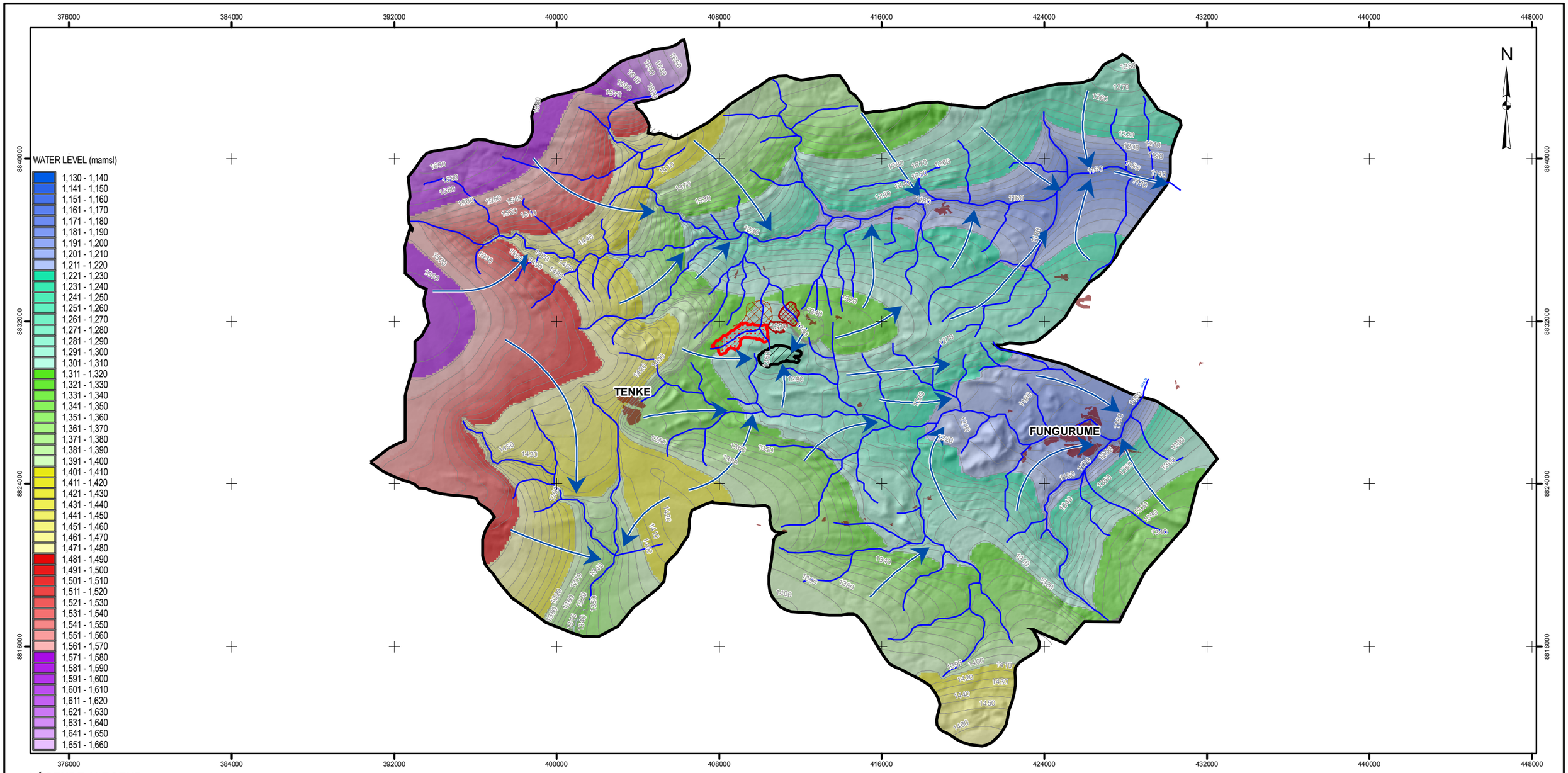
SCENARIO 1D
SIMULATED DRAWDOWN AFTER 8 YEARS OF WELLFIELD ABSTRACTION AND 12 YEARS OF PIT DEWATERING

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007		
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

FIGURE: 48

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated water levels dewatering Scenario 1d.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated water levels dewatering Scenario 1d.pdf



LÉGENDE / LEGEND

- GROUNDWATER FLOW DIRECTION
- WATER LEVEL CONTOUR (mamsl)
- RIVER
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

SCENARIO 1D SIMULATED GROUNDWATER LEVELS AND FLOW DIRECTIONS AFTER 8 YEARS OF WELLFIELD ABSTRACTION AND 12 YEARS OF PIT DEWATERING

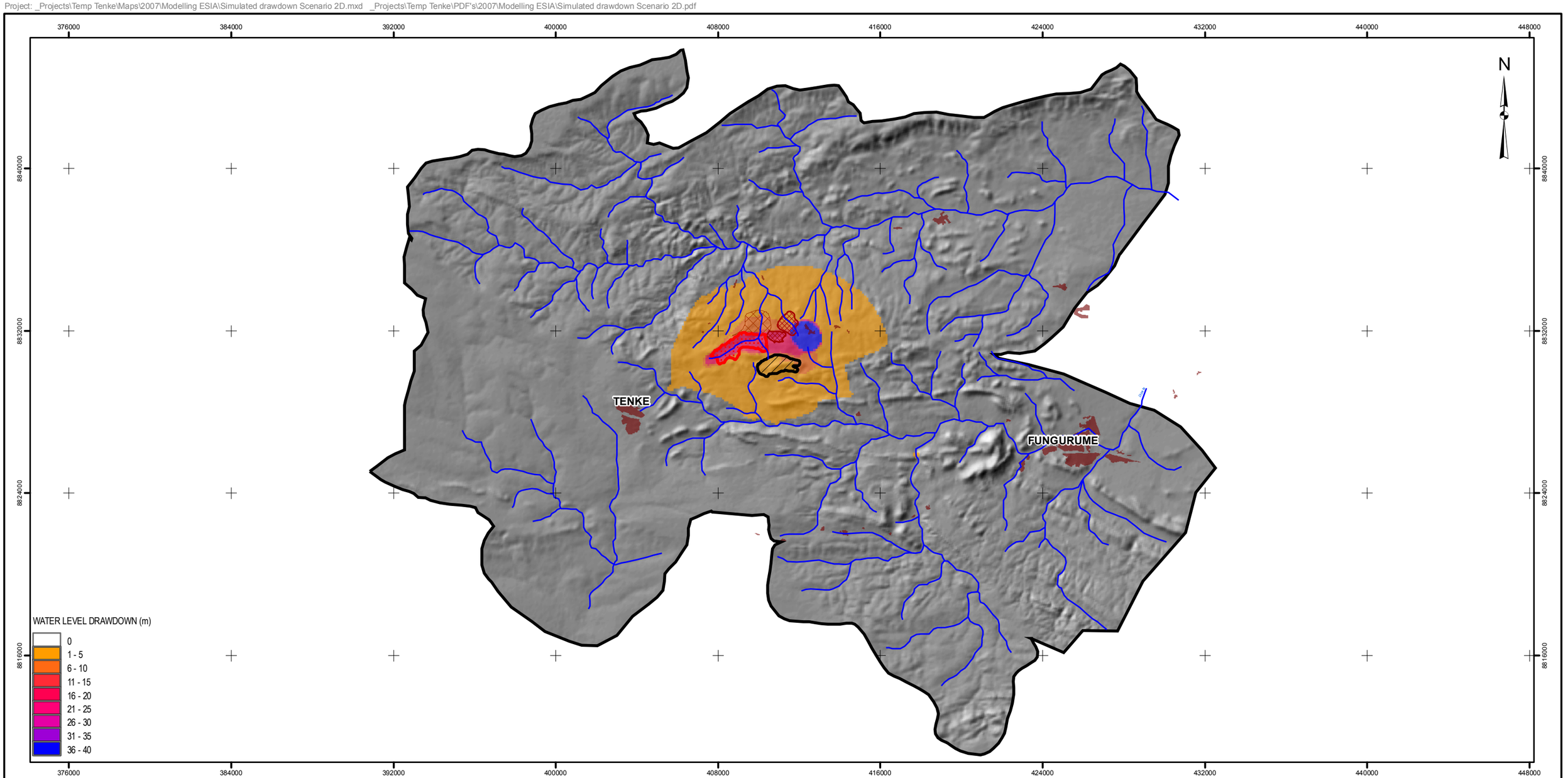
Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	FIGURE: 49	
GIS / SIG	MvdV	30 Jan 2007		
VÉRIFIÉ / CHECK	HvR	30 Jan 2007		
APPROUVÉ / REVIEW	DB	30 Jan 2007		

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated drawdown Scenario 2D.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated drawdown Scenario 2D.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

SCENARIO 2D
SIMULATED DRAWDOWN AFTER 8 YEARS OF WELLFIELD ABSTRACTION

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE SCALE AS SHOWN — REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

FIGURE: 50

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

The model suggests that the drawdown impact of wellfield abstraction is in general less than 20 meters over this eight-year period. The model predicts that the groundwater level would be drawdown by about 40 meters locally around borehole TFWB06A which, as noted earlier, appears to be located within a small compartment largely isolated from the main aquifer system. The area affected over the first eight years of mining by wellfield abstraction by at least one meter or more of drawdown is 58 square kilometers.

Comparison of Figures 50 and 48 indicates that although the areal extent of the drawdown maps of the two scenarios are similar, the drawdown under Scenario 2 is significantly greater. This is because of the lower permeability assigned to the west to east striking aquifer zones acting as barrier boundaries. As a result, pit dewatering will require less pumping under Scenario 2 than Scenario 1.

The groundwater level elevations and flow directions after eight years of mining are depicted in Figure 51 Groundwater flow directions and flow patterns are not significantly modified by the wellfield abstraction from the pre-mining steady-state conditions despite the drawdown of 20 meters that occurred over the eight-year period.

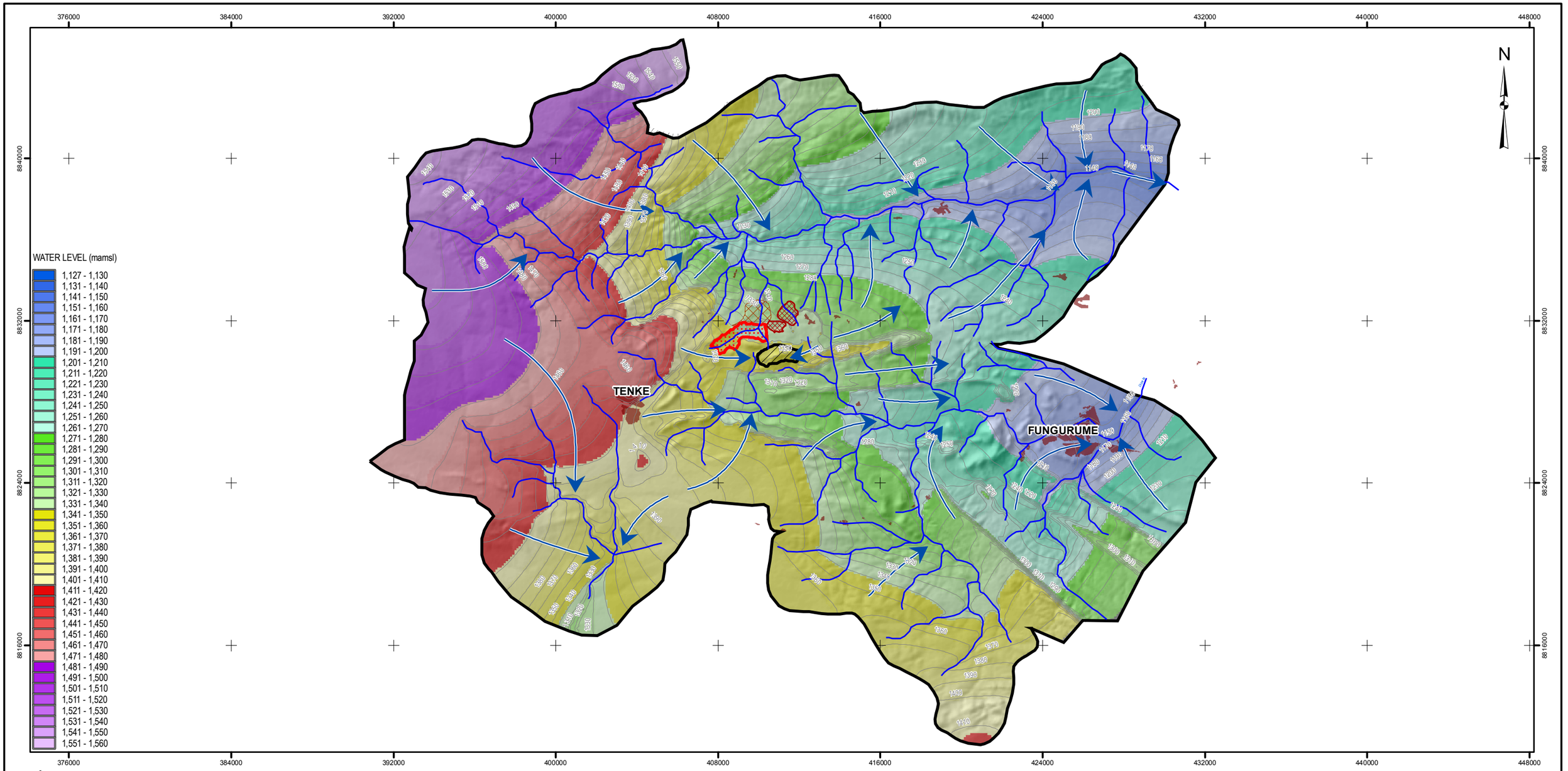
8.6.2.4 Scenario 2d Impact (Final 12 years of mining – pit dewatering in operation)

The impact of abstraction from the wellfield and the pit dewatering over the final twelve years of mining is depicted by the groundwater level drawdown shown in Figure 52.

Figure 52 depicts the drawdown when the pit has been mined to a depth of 80 meters below the water table (i.e., at the end of the mine life after 20 years of operation) for Scenario 2d. The area affected by at least one meter or more of drawdown is 107 square kilometers. The corresponding area affected by at least one meter or more of drawdown with no wellfield abstraction (Scenario 2b, Figure 34) is slightly less, at 103 square kilometers.

The simulated groundwater elevations and flow directions at the end of mining are depicted in Figure 53. The simulated flow patterns are modified in the vicinity of the Kwatebala pit where a drawdown cone has developed over time (over years 9 to 20). Comparison of Figures 53 and 35 indicates that the additional abstraction from the wellfield has minimal impact on the simulated groundwater elevations and flow directions.

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated water levels Scenario 2D.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated water levels Scenario 2D.pdf



LÉGENDE / LEGEND

- GROUNDWATER FLOW DIRECTION
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- WATER LEVEL CONTOUR (mamsl)
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

PROJET / PROJECT

tfm

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

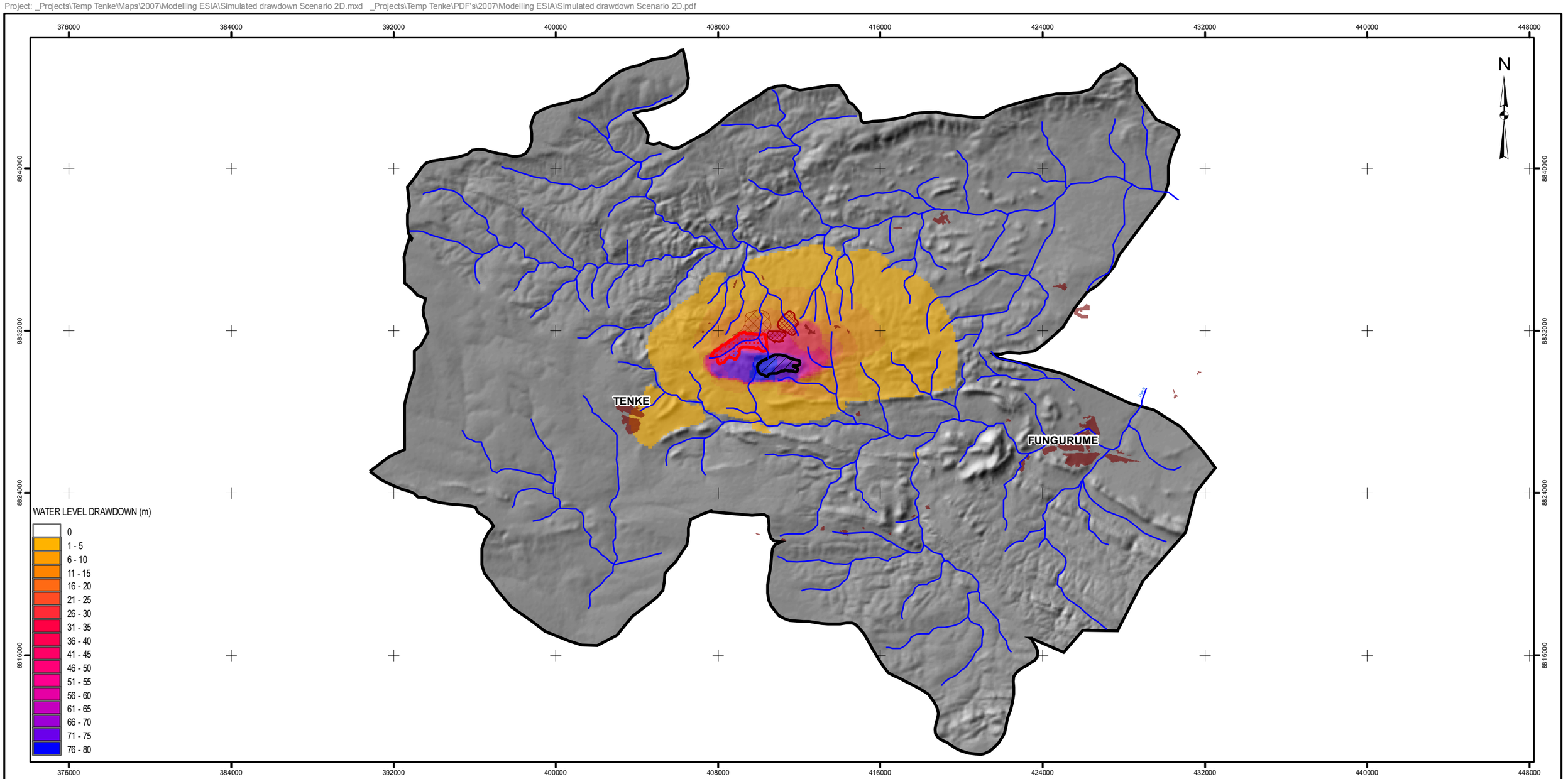
SCENARIO 2D
SIMULATED GROUNDWATER LEVELS AND FLOW DIRECTIONS AFTER 8 YEARS OF WELLFIELD ABSTRACTION

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN — REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

FIGURE: 51

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated drawdown Scenario 2D.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated drawdown Scenario 2D.pdf



LÉGENDE / LEGEND

- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

3 0 3 6 9 12 15

ÉCHELLE 1:190,000 KILOMÈTRES
SCALE 1:190,000 KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

SCENARIO 2D SIMULATED DRAWDOWN AFTER 20 YEARS OF WELLFIELD ABSTRACTION INCLUDING 12 YEARS OF PIT DEWATERING

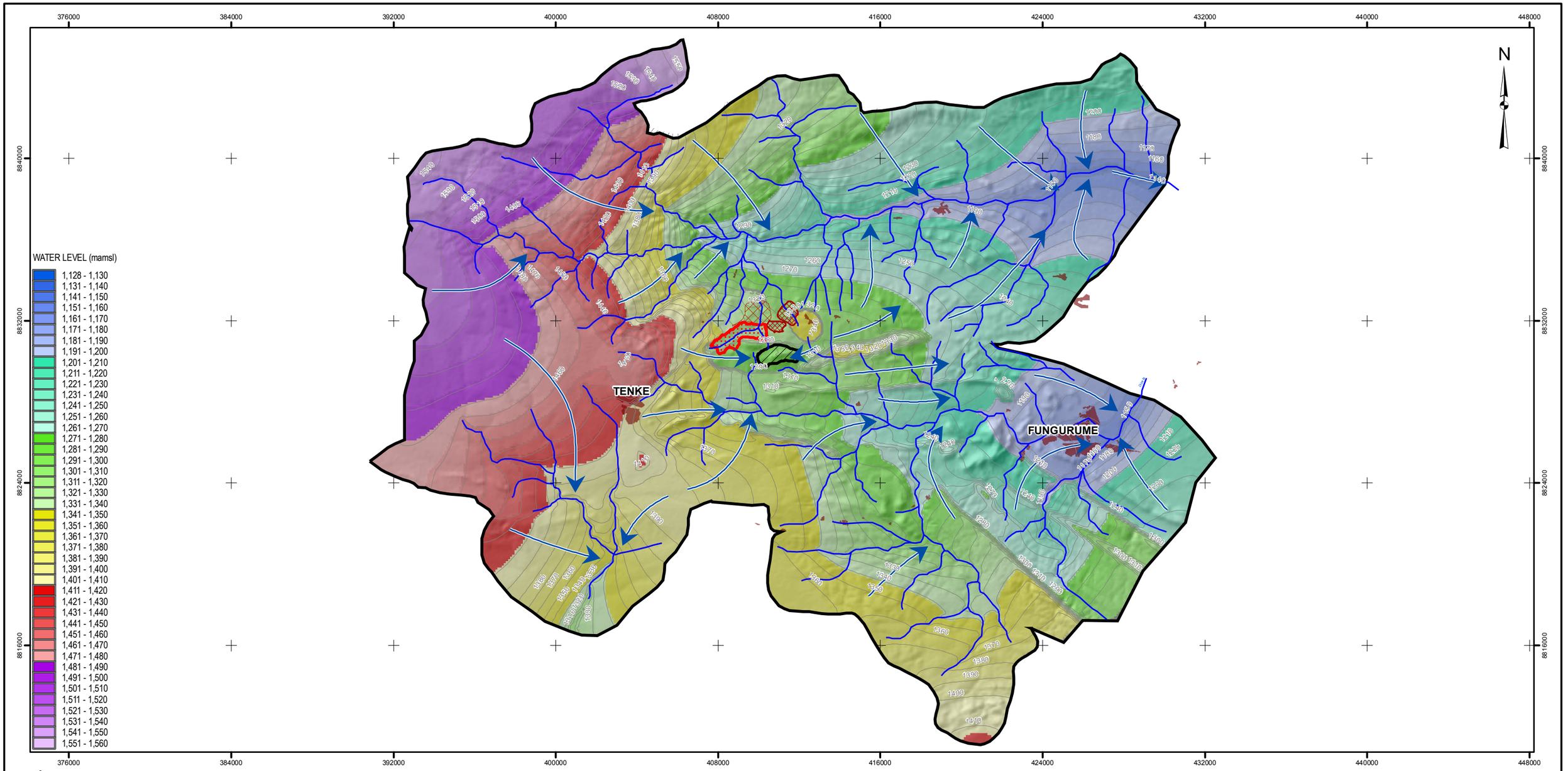
Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN — REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	**FIGURE: 52**
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

Project: _Projects\Temp Tenke\Maps\2007\Modelling ESIA\Simulated water levels dewatering Scenario 2D.mxd _Projects\Temp Tenke\PDF's\2007\Modelling ESIA\Simulated water levels dewatering Scenario 2D.pdf



LÉGENDE / LEGEND

- GROUNDWATER FLOW DIRECTION
- WATER LEVEL CONTOUR (mamsl)
- FOSSE / MINE PIT
- PARC À RÉSIDUS / TAILINGS SITE
- STÉRILES / WASTE ROCK
- MINERAI À FAIBLE TENEUR SUR STÉRILES / LOW GRADE ORE ON WASTE ROCK
- MODELLED AREA
- RIVER
- ÉTABLISSEMENT HUMAIN / SETTLEMENT

RÉFÉRENCE / REFERENCE

Projection : Mercator transverse. Système géodésique : WGS 84 Système de coordonnées : UTM Zone 35S / Projection: Transverse Mercator Datum: WGS 84 Coordinate System: UTM Zone 35S

3 0 3 6 9 12 15

ÉCHELLE 1:190,000KILOMÈTRES
SCALE 1:190,000KILOMETRES

PROJET / PROJECT

PROJET MINIER TENKE FUNGURUME
TENKE FUNGURUME PROJECT
TENKE FUNGURUME MINING SARL

TITRE / TITLE

SCENARIO 2D SIMULATED GROUNDWATER LEVELS AFTER 20 YEARS OF WELLFIELD ABSTRACTION INCLUDING 12 YEARS PIT DEWATERING

Golder Associates
Johannesburg, South Africa

N° PROJET / PROJECT NO. 05-1334-035			ÉCHELLE TELLE QU'INDIQUÉE / SCALE AS SHOWN	REV. 0
DESSIN / DESIGN	HvR	30 Jan 2007	
GIS / SIG	MvdV	30 Jan 2007	
VÉRIFIÉ / CHECK	HvR	30 Jan 2007	
APPROUVÉ / REVIEW	DB	30 Jan 2007	

FIGURE: 53

8.6.2.5 Conclusion

It is concluded from these wellfield scenarios that the average abstraction of 85 liters per second for the water supply is feasible. The additional drawdown impact (combined water supply and pit dewatering) is small compared to the impact of dewatering alone.

8.6.2.6 Groundwater Inflow Rates into the Open Pit During Mining with the Mine Water Supply Wells in Operation

The simulated groundwater inflow rates into the Kwatebala open pit with the simulated wellfield in operation for mine water supply is presented on Figure 54 (Scenarios 1d and 2d). This figure also shows the scenarios where no production wells are in operation (Scenarios 1b and 2b) for comparison. The following general conclusions are drawn from Figures 54 and 54a:

- The abstraction volume required to dewater the open pit will be lower with a water supply wellfield in operation.
- The start of open pit dewatering may be delayed by between 6 to 18 months, depending upon the location of the water supply wellfield.

Figure 54 **Groundwater Inflow Rates into the Open Pit With and Without Wellfield Production Wells in Operation**

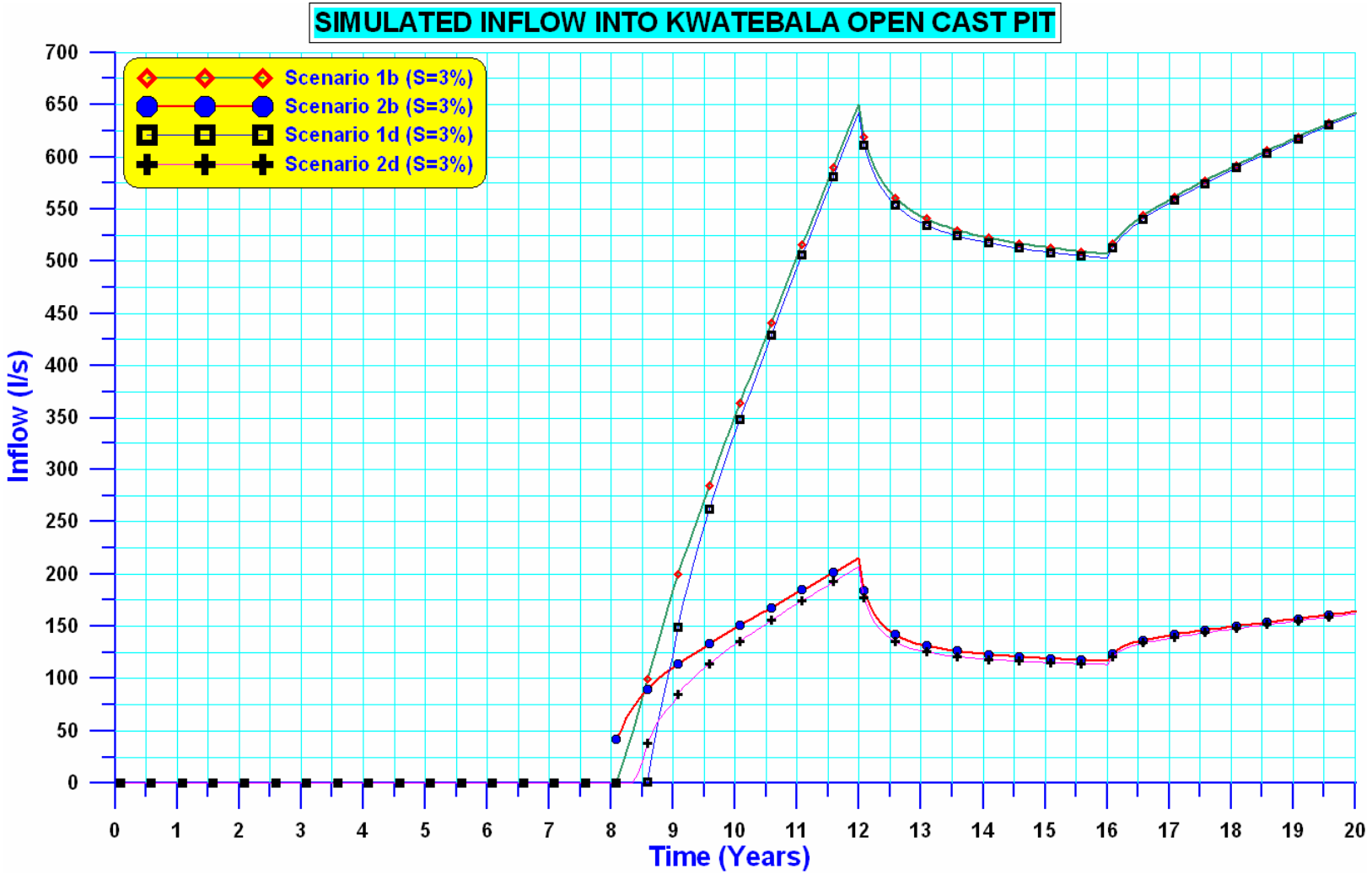
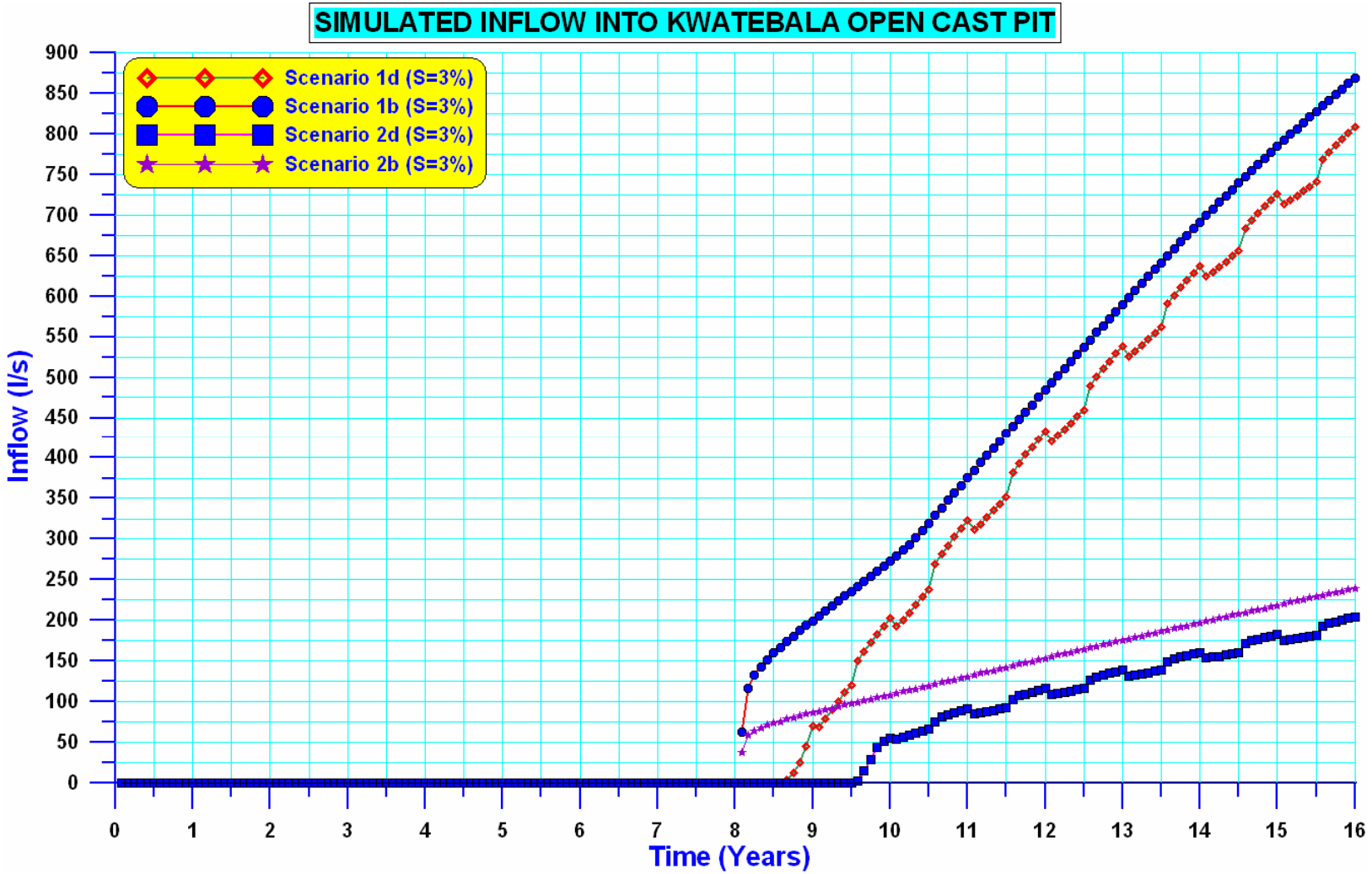


Figure 54a **Groundwater Inflow Rates into the Open Pit With and Without Wellfield Production Wells in Operation – Sensitivity Analysis**



9 CONCLUSIONS

The conclusions derived from the model calibration, sensitivity analyses and predictive simulations are summarized as follow.

9.1 MODEL CALIBRATION, SENSITIVITY AND UNCERTAINTY

The model calibration has identified two possible conceptual models (Scenario 1 and Scenario 2) representing slightly different geological conditions and hydraulic conductivity distributions. The two scenarios are thought to span the likely hydrogeological conditions at Tenke and thus provide a range of potential impacts within which the actual impacts are likely to lie. The Scenario 2 conceptual model results in lower groundwater inflow to the pit since it assumes west to east striking zones of low hydraulic conductivity to the north and south of the proposed Kwatebala pit. The parameter values identified through the model calibration process appear to be appropriate for both scenarios on a regional as well as local scale. Evidence in support of this conclusion includes:

- Calibrated model parameters (hydraulic conductivity, recharge) are consistent with expected values based on field measurements and professional judgment.
- A good match was obtained between simulated and observed values of hydraulic head at the calibration targets.
- The overall configuration of the groundwater level contours in the model are consistent with the internal hydraulic boundaries of divides, topographic highs and lows.
- Model calibration results are sensitive to variations to hydraulic conductivity, especially to hydraulic conductivity variations applied to the RAT/RGS zones.
- The hydraulic conductivity zoning used is compatible with the nature and distribution of the geological units and the geological structures which control the hydrogeology of the study area. It mimics the primary geological regional feature, namely the Dipeta syncline. The hydraulic conductivity distribution is further in correspondence with the geological sequence consisting of dolomite, sandstone and shale that ranges from relatively high to low permeability. The large-scale, effective hydraulic conductivity values identified in the model calibration compare well with the hydraulic conductivity (transmissivity) data.
- The background recharge of 240 millimeters per year is consistent with previous estimates.

- The steady state water balance for the modeled area is in good comparison with the total simulated surface water flows for the lower Dipeta and lower Mofia rivers which are primarily fed by groundwater discharge.
- The model structure and parameters used in the calibrated model appear appropriate and reasonable. The model-calculated hydraulic heads are consistent with the observed heads and the overall shape of the water table is consistent with that expected and discussed in the conceptual model. The model shows groundwater recharge occurring and discharging within the surface drainages consistent with the conceptual model.
- The major uncertainty appears to be related to the geological conditions and the nature and extent of the low permeability units, both horizontally and vertically. These low permeability units act to compartmentalize the groundwater flow system and thus can result in significantly different hydrogeological conditions (both in terms of groundwater elevations and hydraulic conductivity) over short distances. Geological data and indirect interpretation of morphological features have been used to interpret the extent of low permeability units. This uncertainty is addressed by incorporating two different geological interpretations into the model and by presenting the results as a range rather than as a single-point estimate. As additional boreholes are drilled the extent of these units will be better known and the model can be revised to reflect the improved knowledge.
- The model represents a generalized simplification of the geology and groundwater flow system at Tenke. These assumptions are believed to be reasonable based on current site knowledge and the overall purpose of the groundwater flow model.

9.2 PREDICTIVE SIMULATIONS

9.2.1 Pit Inflows

Scenario 1 - Model results suggest that groundwater inflow to the pit will increase over time as the pit is deepened reaching about 650 liters per second at the end of the mining process (20 years).

Scenario 2 - Model results suggest that groundwater inflow to the pit will increase over time as the pit is deepened reaching about 200 liters per second at the end of the mining process (20 years).

A sensitivity analysis indicates that the results are not particularly sensitive to the pit dewatering plan or aquifer storativity.

Pit inflow estimates under Scenario 1 are about three times greater than Scenario 2. This is a result of the higher permeability values used in Scenario 1 which results in a larger capture zone for the pit. A larger capture zone enables a greater proportion of the spatial recharge to ultimately enter the pit as groundwater inflow.

The simulated inflows can be classified as "high" and it can therefore be concluded that groundwater inflow may pose a risk to mining and that efficient and safe dewatering of the mine may not be accomplished by using "in-pit" dewatering. A cut-off curtain of wells may be needed around the pit perimeter.

9.2.2 Changes in Groundwater Levels and Seepage Pathways During Pit Dewatering

Scenario 1. The area affected by one meter or more of drawdown is 160 square kilometers.

Prior to dewatering seepage from the tailings facility and the southern part of the waste rock facilities and ore stockpiles will migrate to the south and southeast (towards the Kwatebala pit) while seepage from the northern parts of the waste rock facilities and ore stockpiles will migrate towards the north and the Mofia River. This is due to simulated presence of a groundwater divide located between the tailings facility and the waste rock and ore stockpiles.

Once dewatering commences seepage from the tailings facility will be captured by the pit. However, seepage from the northern parts of the waste rock facilities and ore stock piles will migrate northward toward the Mofia River.

Scenario 2. The area affected by 1-meter or more of drawdown is 103 square kilometers.

As with Scenario 1, seepage from the tailings storage facility and the southern part of the waste rock facilities and ore stockpiles will migrate to the south and southeast (towards the Kwatebala pit) while seepage from the northern parts of the waste rock facilities and ore stockpiles will migrate towards the north and the Mofia River prior to dewatering. Once dewatering commences seepage from the tailings facility will be captured by the pit. However, seepage from the northern parts of the waste rock facilities and ore stock piles will migrate to the Mofia River.

9.2.3 Post-Closure

Scenario 1 - Once mining and dewatering cease the recovery in the groundwater levels will form a pit lake within the open pit. The modeling indicates that the pit lake water level will recover to a new equilibrium level about 20 years following the end of mining.

The steady state post closure simulation shows that seepage from the mine facilities and pit lake could reach the Mofia and Dipeta rivers.

Scenario 2 - Once mining and dewatering cease, a pit lake will form within the open pit. The modeling indicates that the pit lake water level will recover to a new equilibrium level about 60 years following the end of mining.

The steady state post closure simulation shows that seepage from the mine facilities and pit lake could reach the Mofia and Dipeta rivers.

9.2.4 Impact of Mine Dewatering and Closure on Baseflow, Springs and Wells and Gallery Forest

Scenario 1 - Without mitigation the baseflow in the Dipeta River could decrease from about 240,000 cubic meters per day pre-mining to 200,000 cubic meters per day at the end of mining. Dewatering impacts on the baseflow of the Mofia and Tshilongo Rivers will be small to negligible. Baseflow would recover following the cessation of dewatering operations returning to near pre-mining conditions.

Scenario 2 – There would be only a minimal impact on the river baseflow. Discharge of excess mine dewatering water to the Dipeta River will provide mitigation of this impact. Dewatering impacts on the baseflow of the Mofia and Tshilongo Rivers will be negligible. Baseflow would recover following the cessation of dewatering operations returning to near pre-mining conditions.

Gallery Forest - There could be impacts on the groundwater levels below areas of gallery forest sustained by groundwater discharge. The impacts will be progressive, gradually increasing over the duration of pit dewatering and then extend into the closure and post-closure period as the groundwater system re-establishes to a new equilibrium. The impacts would be greatest in the Kasana drainage north of the waste rock stockpile and similar north-flowing tributaries reaching the Mofia River in proximity to the mine. Discharge of excess dewatering water to these drainages (particularly in the dry season) could mitigate the impacts. Mitigation post-closure (upon termination of the active dewatering system) would involve continued use of one of the water supply

production wells in the amount of about 45 liters per second. Use of a well for longer-term mitigation would only slightly alter the time required for the pit to flood and reach a new equilibrium. An alternative mitigation measure could be the development of irrigated farmland on the hillside perimeter of the gallery forest. Seepage of excess irrigation water could replenish the reduced baseflow in the valley bottom.

Springs and Wells - There could be adverse impacts to local springs and wells used by the Mwonga Muteba community for water supply purposes. The impacts will be progressive gradually increasing over the duration of pit dewatering and then extend into the closure and post-closure period as the groundwater system re-establishes to a new equilibrium. It is predicted that 15 to 16 springs could be lost as a source of supply over the mining period. Over the long-term post closure period, it is possible that up to five springs may not be re-established post-closure and several springs will show only seasonal rather than year round discharge. Mitigation for these impacts can be addressed through the provision of deep boreholes equipped with hand pumps.

9.2.5 Impacts of Mine Water Supply Wellfield

A wellfield layout has been incorporated into the model to simulate the effects of abstracting 55 liters per second during the six-month wet season and 115 liters per second during the six-month dry season on the groundwater regime for the 16-year duration of the mine. The modeling has shown that:

- The average abstraction of 85 liters per second at the wellfield location is feasible.
- Pumping the wellfield results in little additional drawdown of the groundwater system beyond that predicted as a result of mine dewatering.
- Operation of the wellfield will reduce the quantity of water required to be handled by the pit dewatering system.
- The start of open pit dewatering may be delayed by between 6 to 18 months, depending upon the location of the water supply wellfield.

9.2.6 Sensitivity of Model Results to Dewatering Plan

A sensitivity analysis of the model results to a modified dewatering plan (assuming a shorter dewatering period but larger pit extent) was completed. The model results indicated similar pit inflows and similar or slightly smaller impacts to the groundwater system from dewatering. It is therefore concluded that

mitigation measures developed based on the range of impacts determined from Scenarios 1 and 2 for the base case conditions should address the overall groundwater impacts from the Tenke Project.

10 REFERENCES

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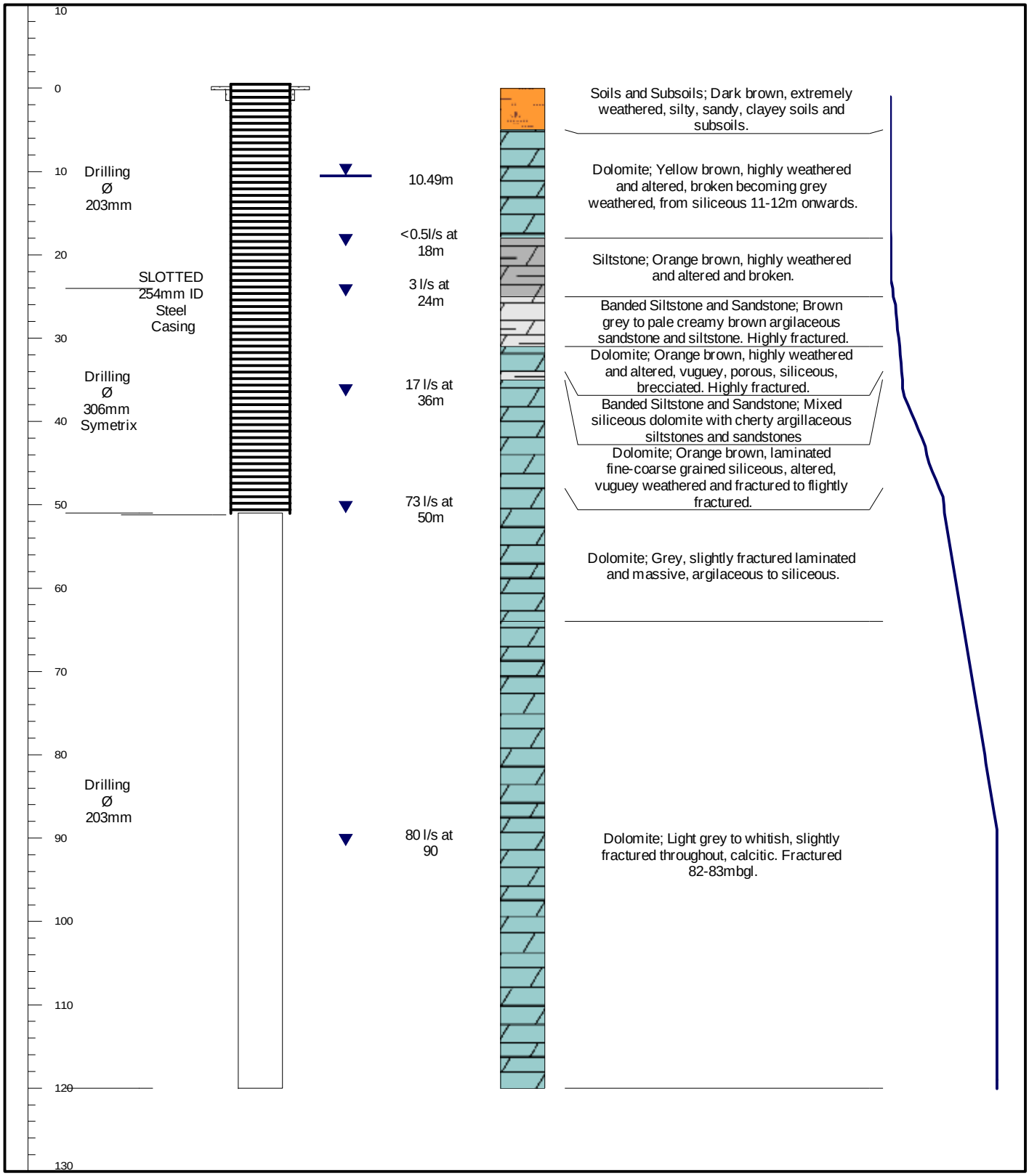
ATTACHMENT 1

GEOLOGICAL LOGS AND WELL CONSTRUCTION DIAGRAMS

Location:	UTM 35 L	**Date drilled:**	11/1/06	**Collar Height (magl):**	0.21	Borehole No.	
Y co-ordinate:	8835043	**Depth (mbgl):**	120	**SWL (mbgl):**	10.49	**CC1**	
X co-ordinate:	423573	**Casing Depth (m)**	51.2	**Blow Yield (l/s):**	>100		
Elevation (mamsl):	1182						

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 50.00 100.00 150.00

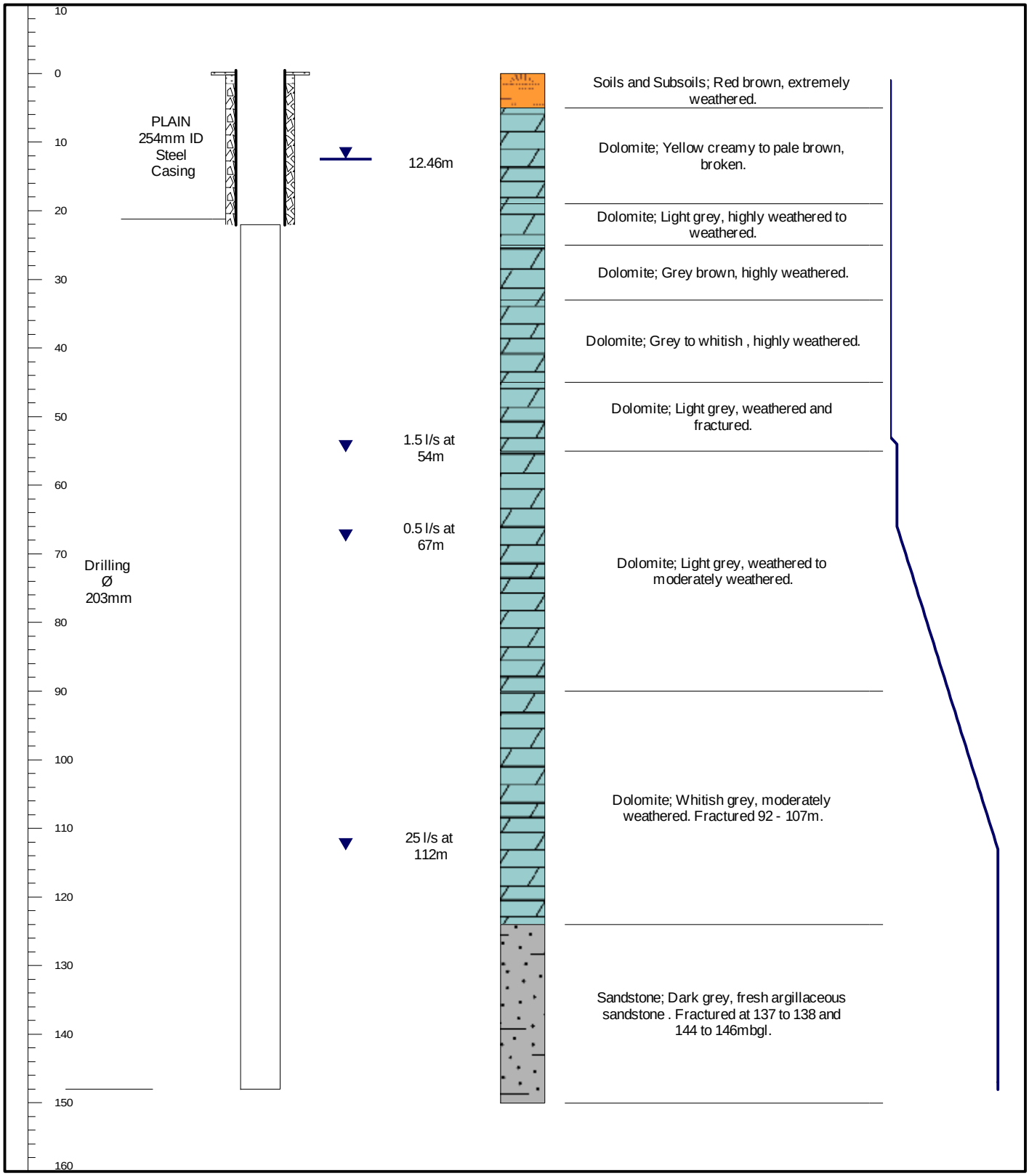


TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	10/31/06	**Collar Height (magl):**	0.22	Borehole No.	
Y co-ordinate:	8835658	**Depth (mbgl):**	148	**SWL (mbgl):**	12.46	**CC2**	
X co-ordinate:	424276	**Casing Depth (m)**	21.2	**Blow Yield (l/s):**	25		
Elevation (mamsl):	1184						

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 10.00 20.00

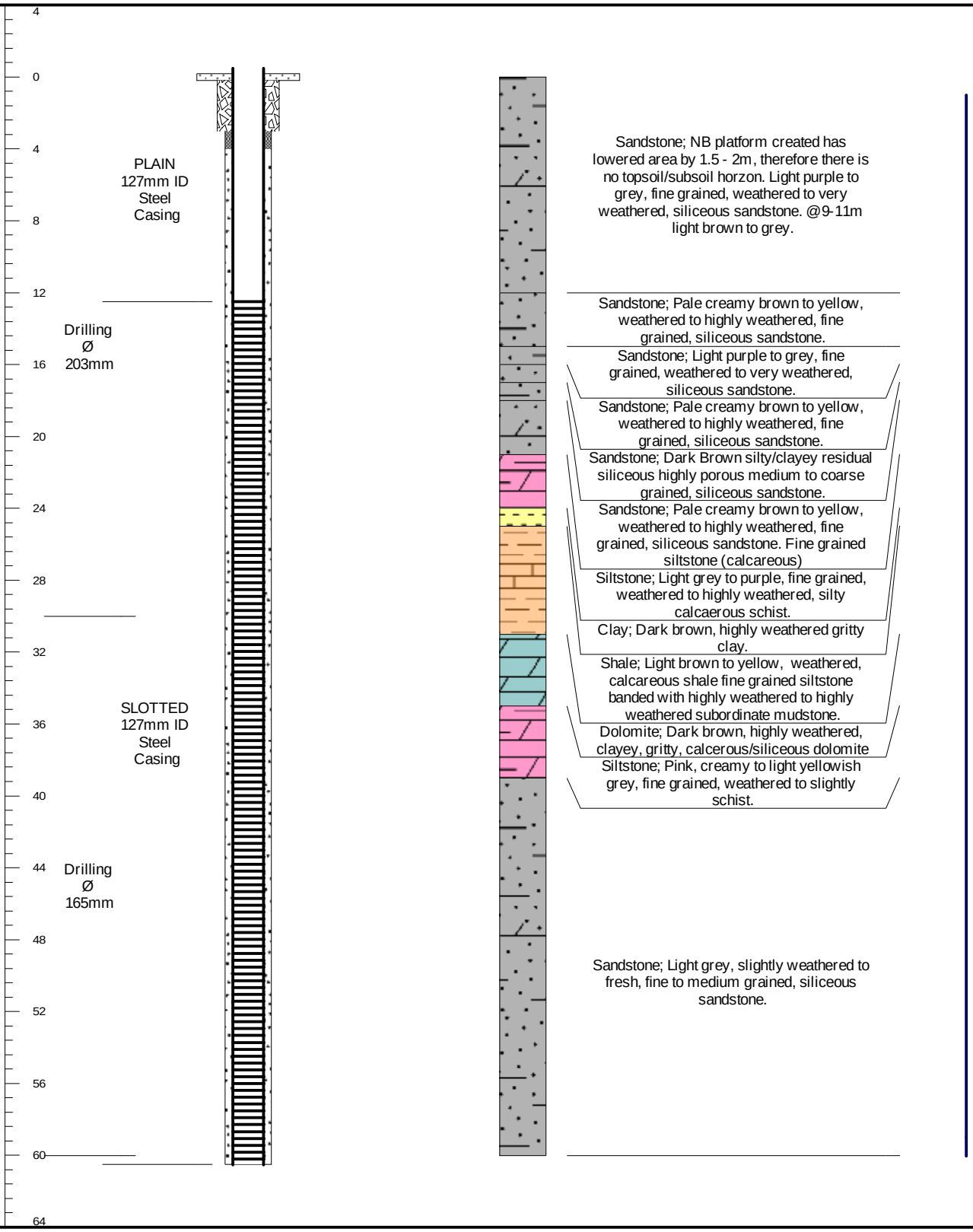


TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	8/30/06	**Collar Height (magl):**	0.49	Borehole No.	
Y co-ordinate:	8830488	**Depth (mbgl):**	60.5	**SWL (mbgl):**	Dry	**TFEB01**	
X co-ordinate:	408956	**Casing Depth (m)**	60.5	**Blow Yield (l/s):**	Dry		
Elevation (mamsl):							

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) -1.00 -0.50 0.00 0.50 1.00

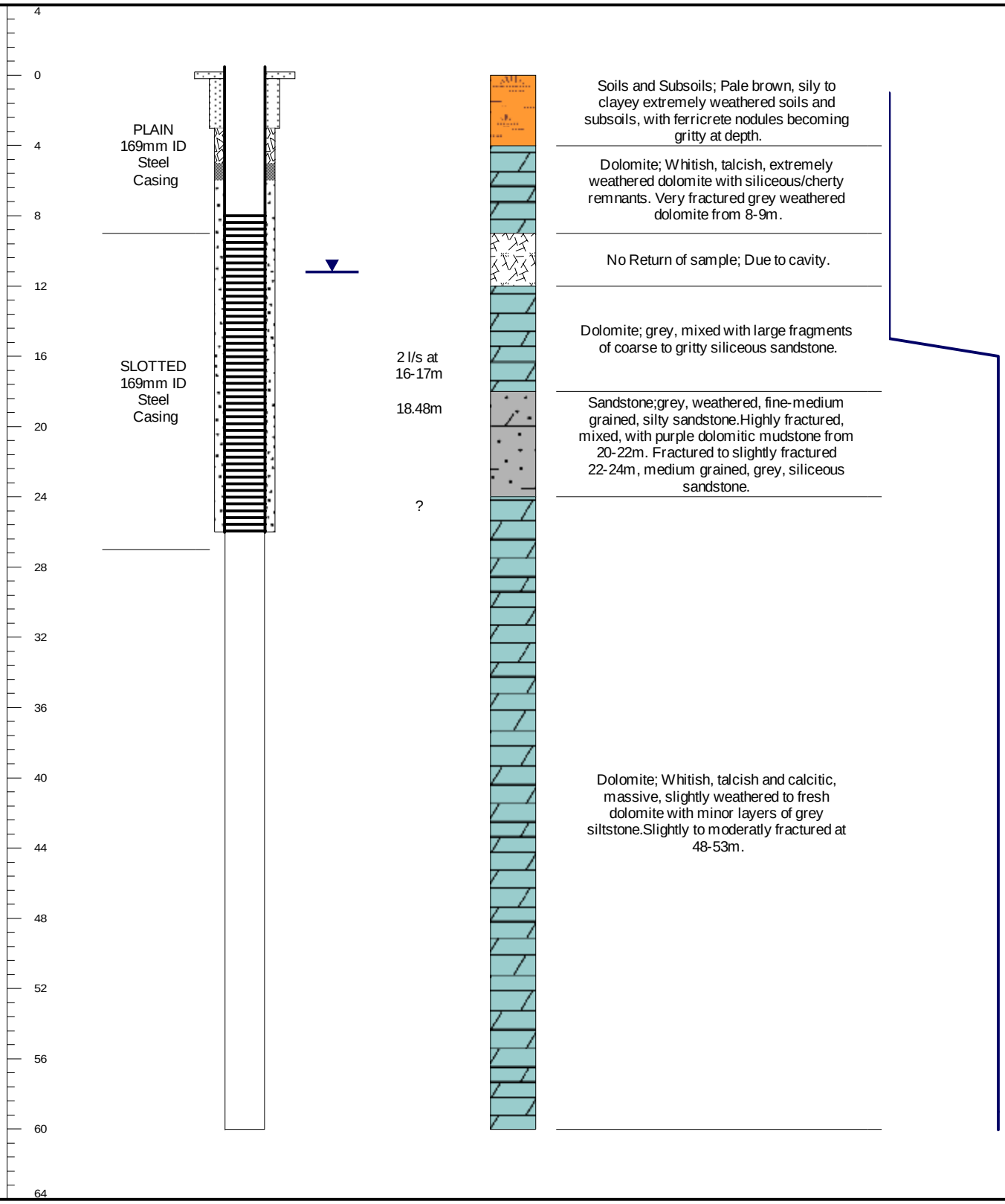


TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	8/25/06	**Collar Height (magl):**	0.27	Borehole No.	
Y co-ordinate:	8831730	**Depth (mbgl):**	60	**SWL (mbgl):**	11.2	**TFEB02**	
X co-ordinate:	411782	**Casing Depth (m)**	26	**Blow Yield (l/s):**	2.5		
Elevation (mamsl):	1396						

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 0.50 1.00 1.50 2.00

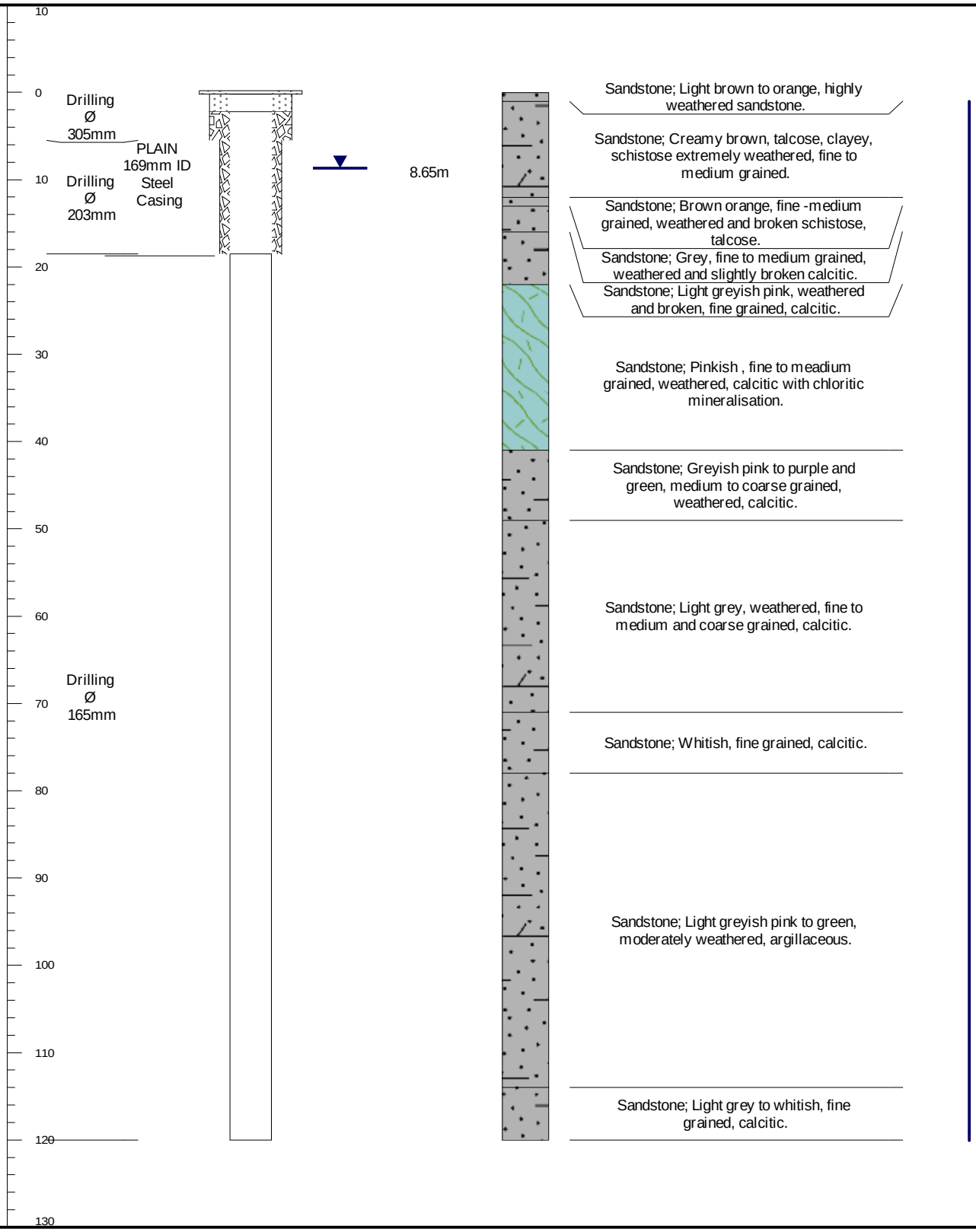


TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	11/8/06	**Collar Height (magl):**	0.31	Borehole No.	
Y co-ordinate:	8830869	**Depth (mbgl):**	120	**SWL (mbgl):**	8.65	**TFEB03**	
X co-ordinate:	412364	**Casing Depth (m)**	26	**Blow Yield (l/s):**	Dry		
Elevation (mamsl):	1379						

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) -1.00 -0.50 0.00 0.50 1.00

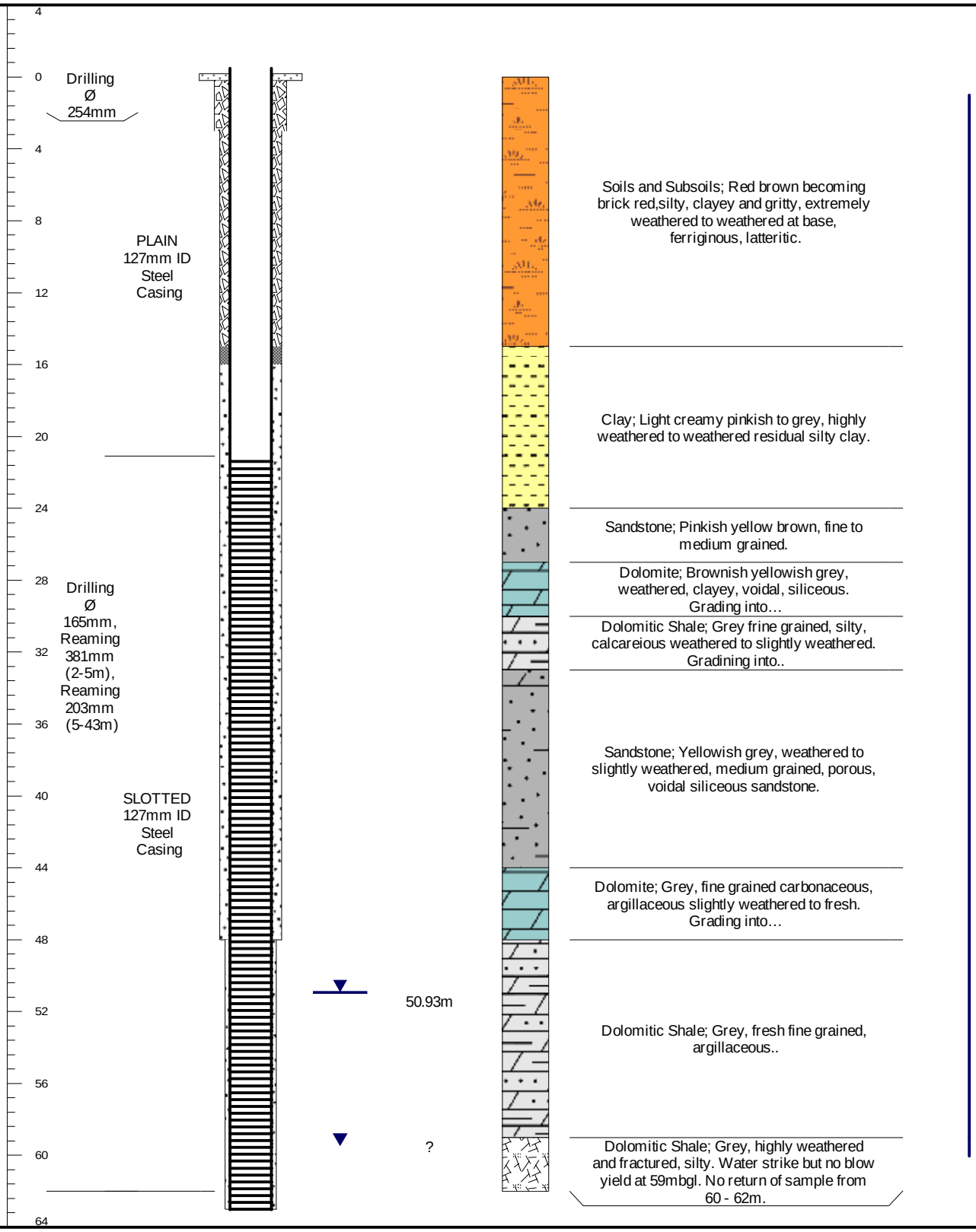


TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	8/28/06	**Collar Height (magl):**	0.68	Borehole No.	
Y co-ordinate:	8830210.5	**Depth (mbgl):**	60	**SWL (mbgl):**	50.93	**TFEB05**	
X co-ordinate:	408296	**Casing Depth (m)**	60	**Blow Yield (l/s):**	LOA		
Elevation (mamsl):	1405						

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) -1.00 -0.50 0.00 0.50 1.00

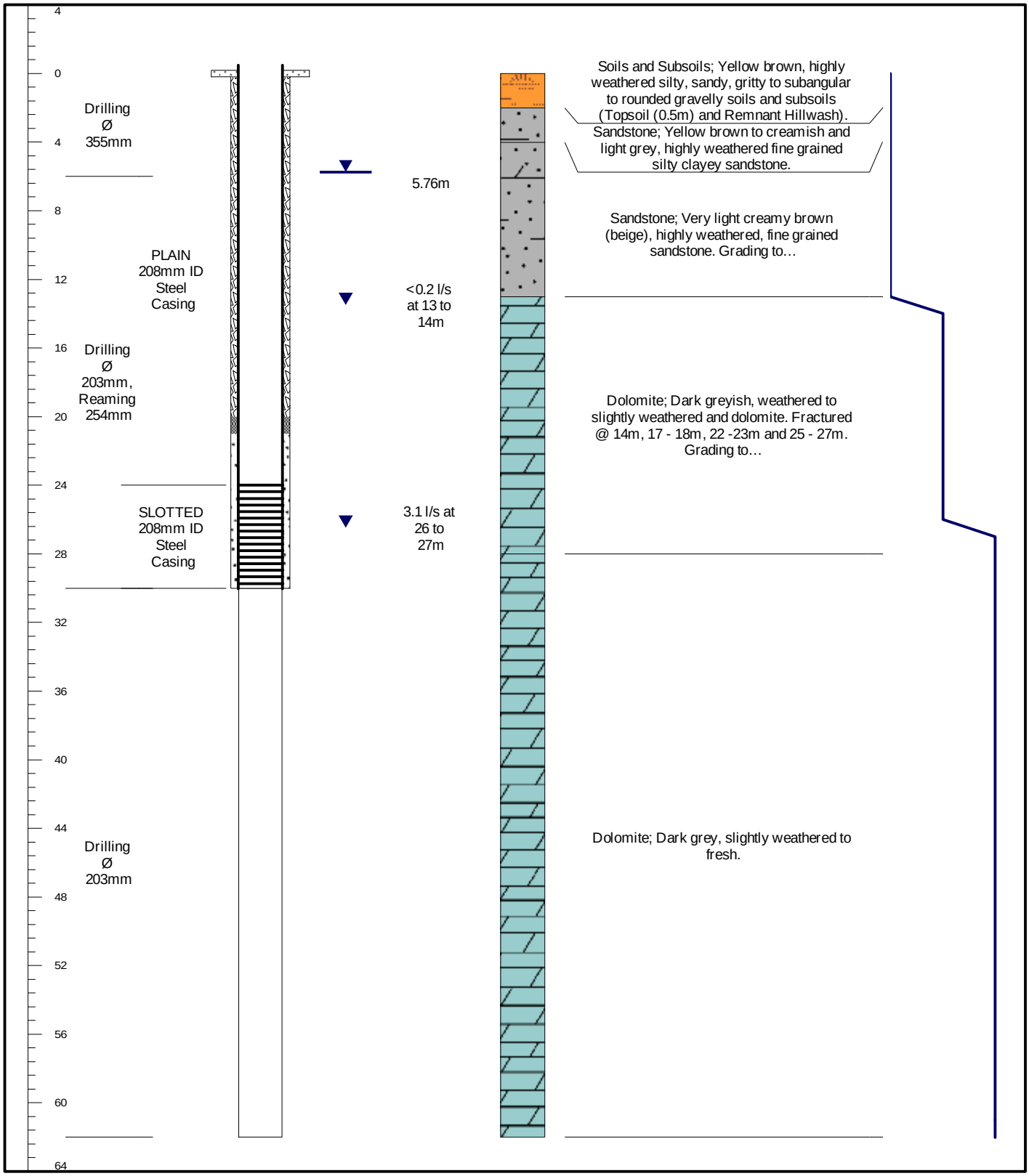


TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	8/29/06	**Collar Height (magl):**	0.22	Borehole No.	
Y co-ordinate:	8831706	**Depth (mbgl):**	62	**SWL (mbgl):**	5.76	**TFEB06**	
X co-ordinate:	407199	**Casing Depth (m)**	30	**Blow Yield (l/s):**	2		
Elevation (mamsl):	1390						

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 2.00 4.00 6.00



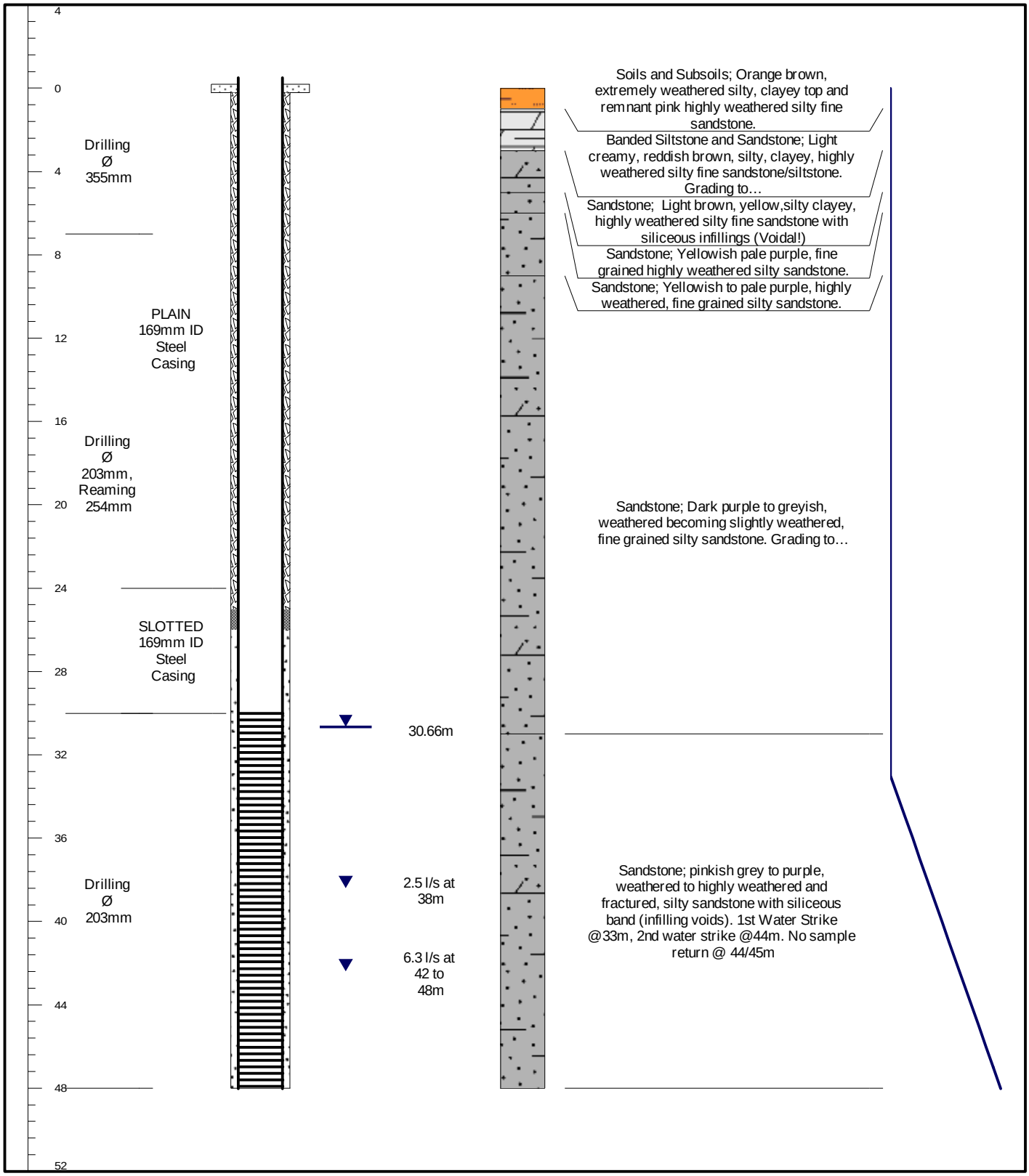
TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	10/20/06	**Collar Height (magl):**	0.14
Y co-ordinate:	8831969.94	**Depth (mbgl):**	48	**SWL (mbgl):**	30.66
X co-ordinate:	408507.88	**Casing Depth (m)**	48	**Blow Yield (l/s):**	8
Elevation (mamsl):	1370				

Borehole No.
TFEB07

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 2.00 4.00 6.00

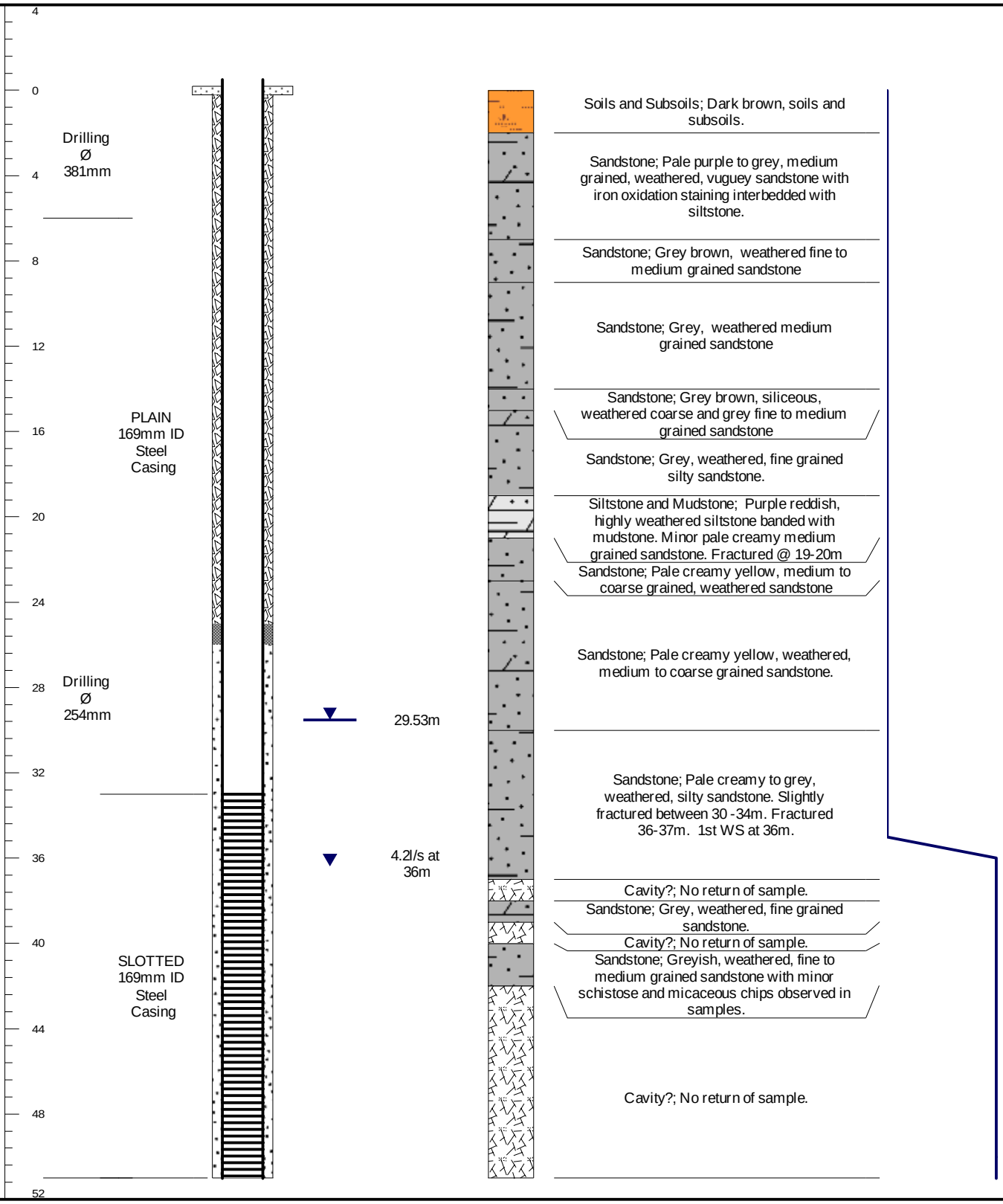


TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	10/22/06	**Collar Height (magl):**	0.47	Borehole No.	
Y co-ordinate:	8832439	**Depth (mbgl):**	51	**SWL (mbgl):**	29.53	**TFEB08**	
X co-ordinate:	409032	**Casing Depth (m)**	51	**Blow Yield (l/s):**	4		
Elevation (mamsl):	1366						

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 2.00 4.00



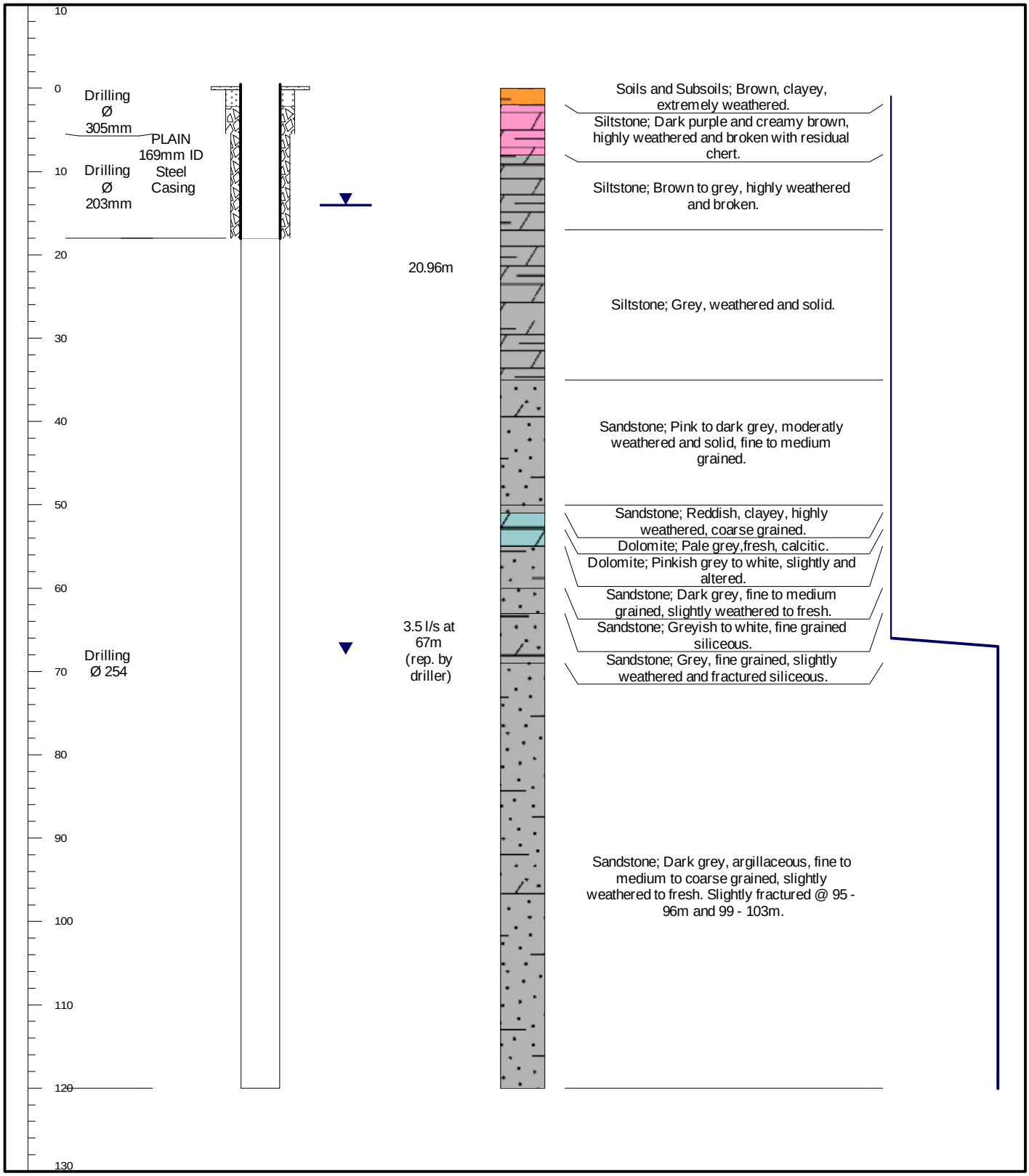
TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	9/1/06	**Collar Height (magl):**	0.35
Y co-ordinate:	8829434.555539999	**Depth (mbgl):**	120	**SWL (mbgl):**	20.96
X co-ordinate:	412150.397591	**Casing Depth (m)**	18	**Blow Yield (l/s):**	3
Elevation (mamsl):	1342				

Borehole No.
TFEB09

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 1.00 2.00



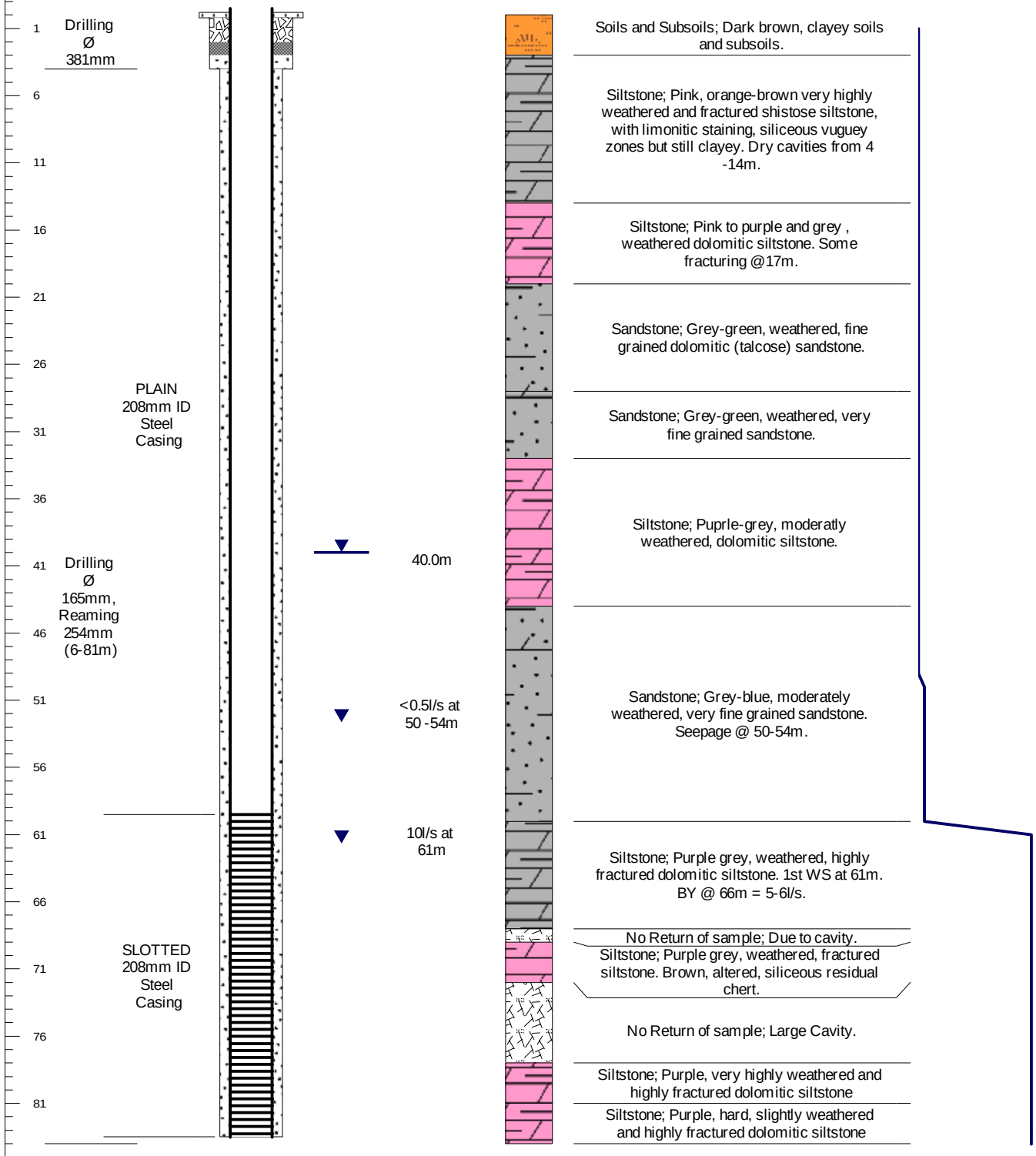
TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	9/5/06	**Collar Height (magl):**	0.27
Y co-ordinate:	8830033.618620001	**Depth (mbgl):**	83.5	**SWL (mbgl):**	40
X co-ordinate:	406616.645622	**Casing Depth (m)**	83.5	**Blow Yield (l/s):**	11
Elevation (mamsl):	1391				

Borehole No.
TFEB10

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 2.50 5.00 7.50 10.00

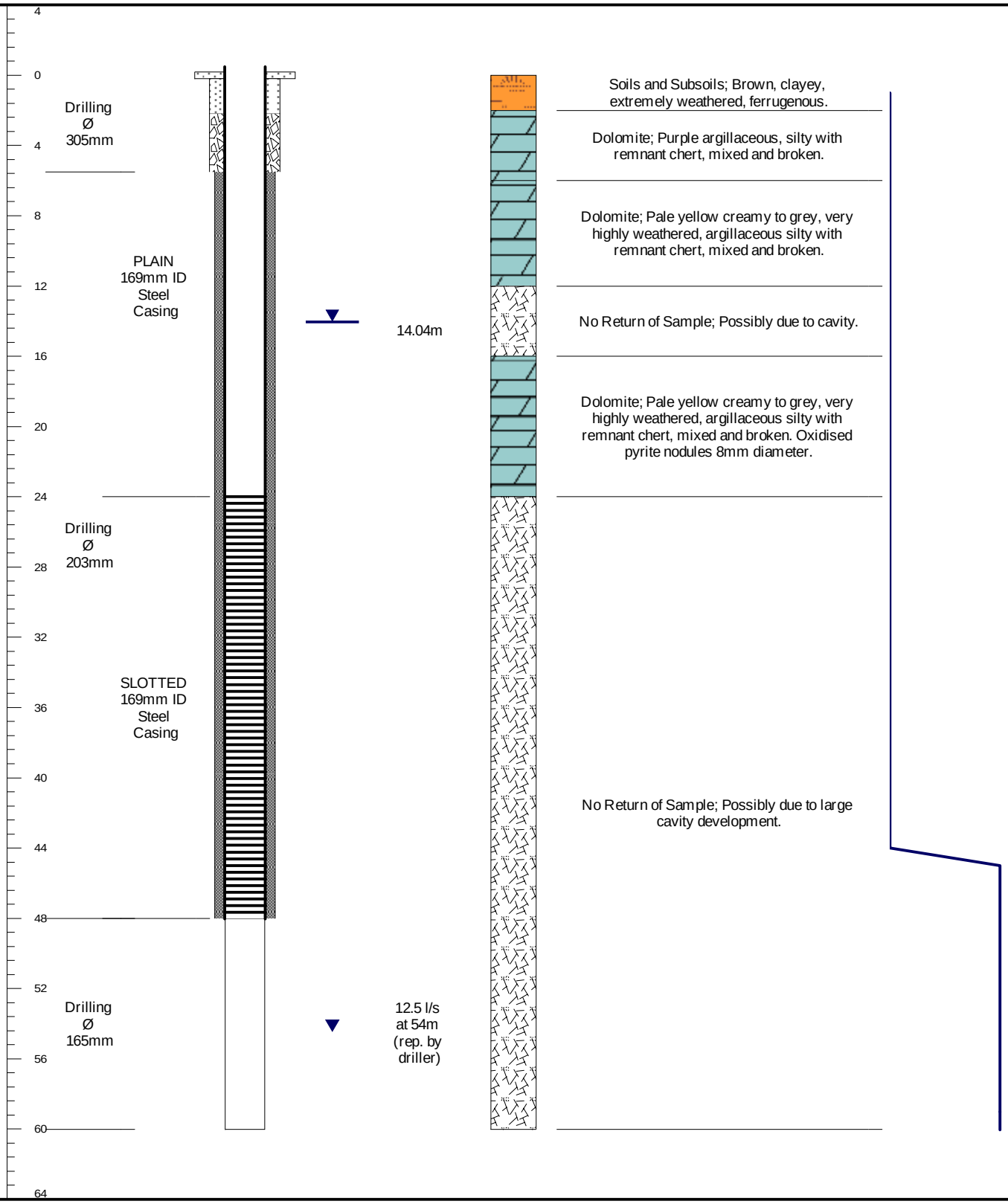


TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	9/3/06	**Collar Height (magl):**	0.39	Borehole No.	
Y co-ordinate:	8827768	**Depth (mbgl):**	60	**SWL (mbgl):**	14.04	**TFEB11**	
X co-ordinate:	414384	**Casing Depth (m)**	48	**Blow Yield (l/s):**	>12		
Elevation (mamsl):	1273						

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 5.00 10.00

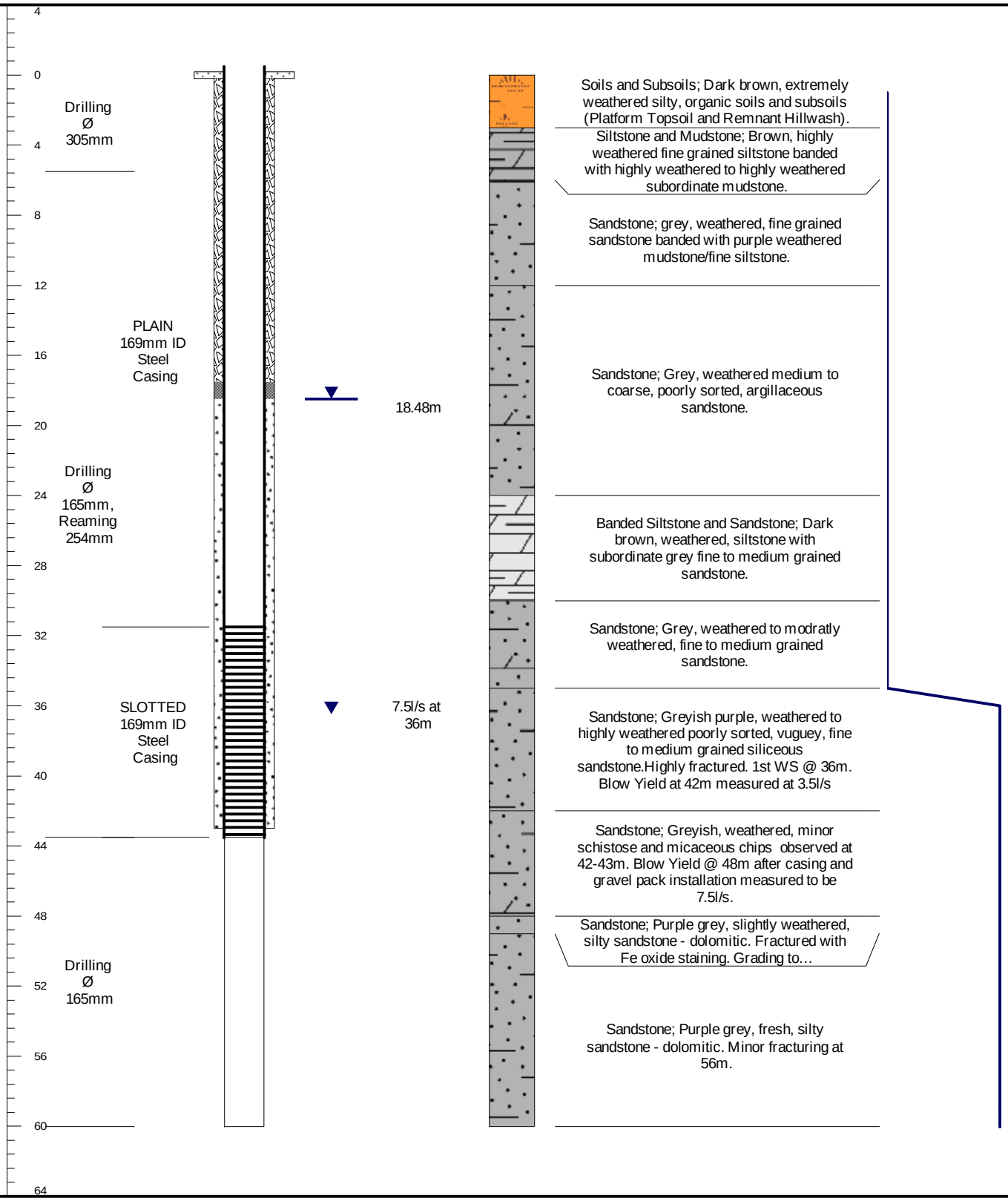


TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	10/23/06	**Collar Height (magl):**	0.3	Borehole No.	
Y co-ordinate:	8831664	**Depth (mbgl):**	60	**SWL (mbgl):**	18.48	**TFEB12**	
X co-ordinate:	410465	**Casing Depth (m)**	43.5	**Blow Yield (l/s):**	7.5		
Elevation (mamsl):	1377						

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 2.00 4.00 6.00



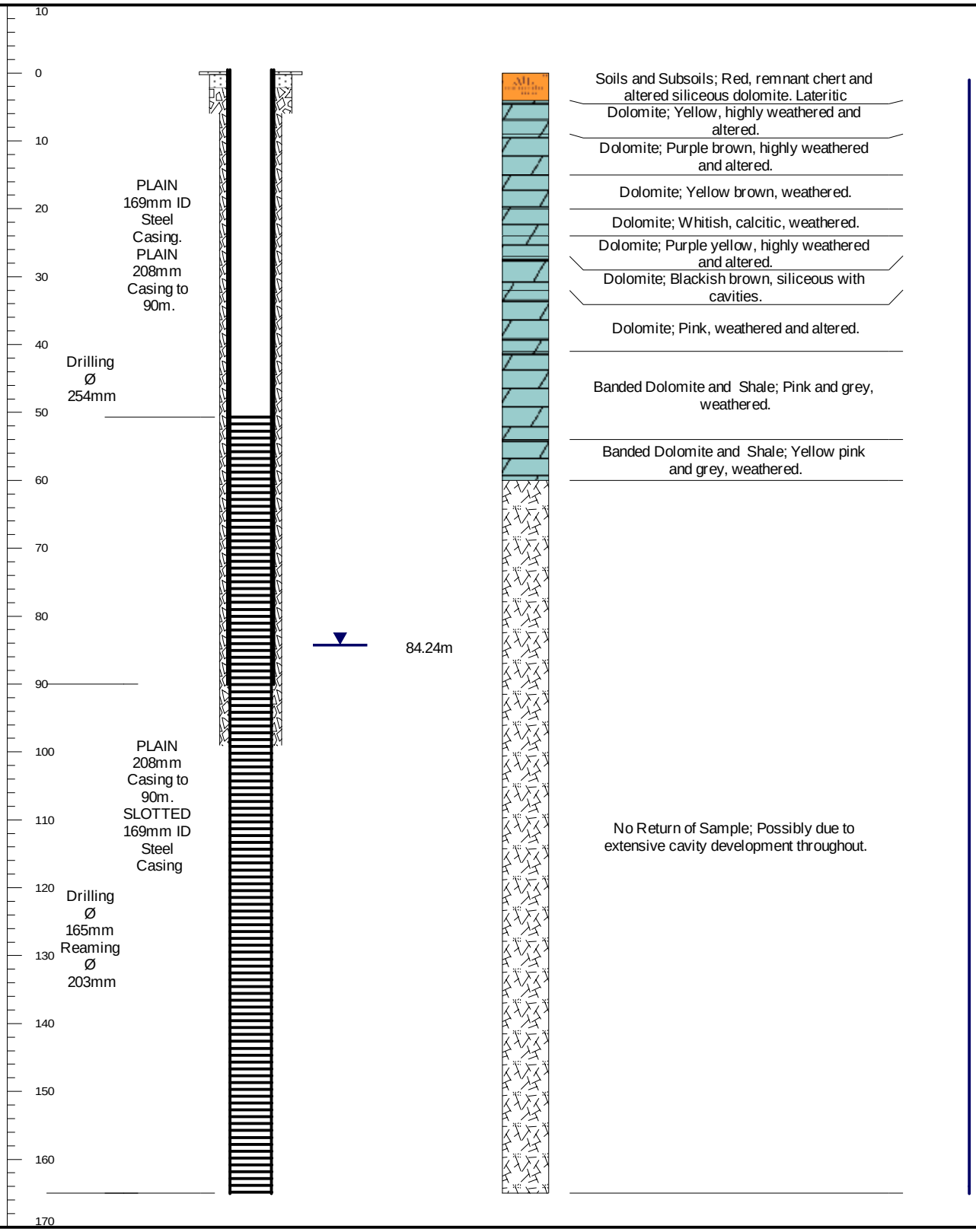
TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	8/11/06	**Collar Height (magl):**	0.1
Y co-ordinate:	8830653.935000001	**Depth (mbgl):**	165	**SWL (mbgl):**	84.24
X co-ordinate:	411200.335	**Casing Depth (m)**	165	**Blow Yield (l/s):**	LOA
Elevation (mamsl):	1429				

Borehole No.
TFWB01A

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) -1.00 -0.50 0.00 0.50 1.00

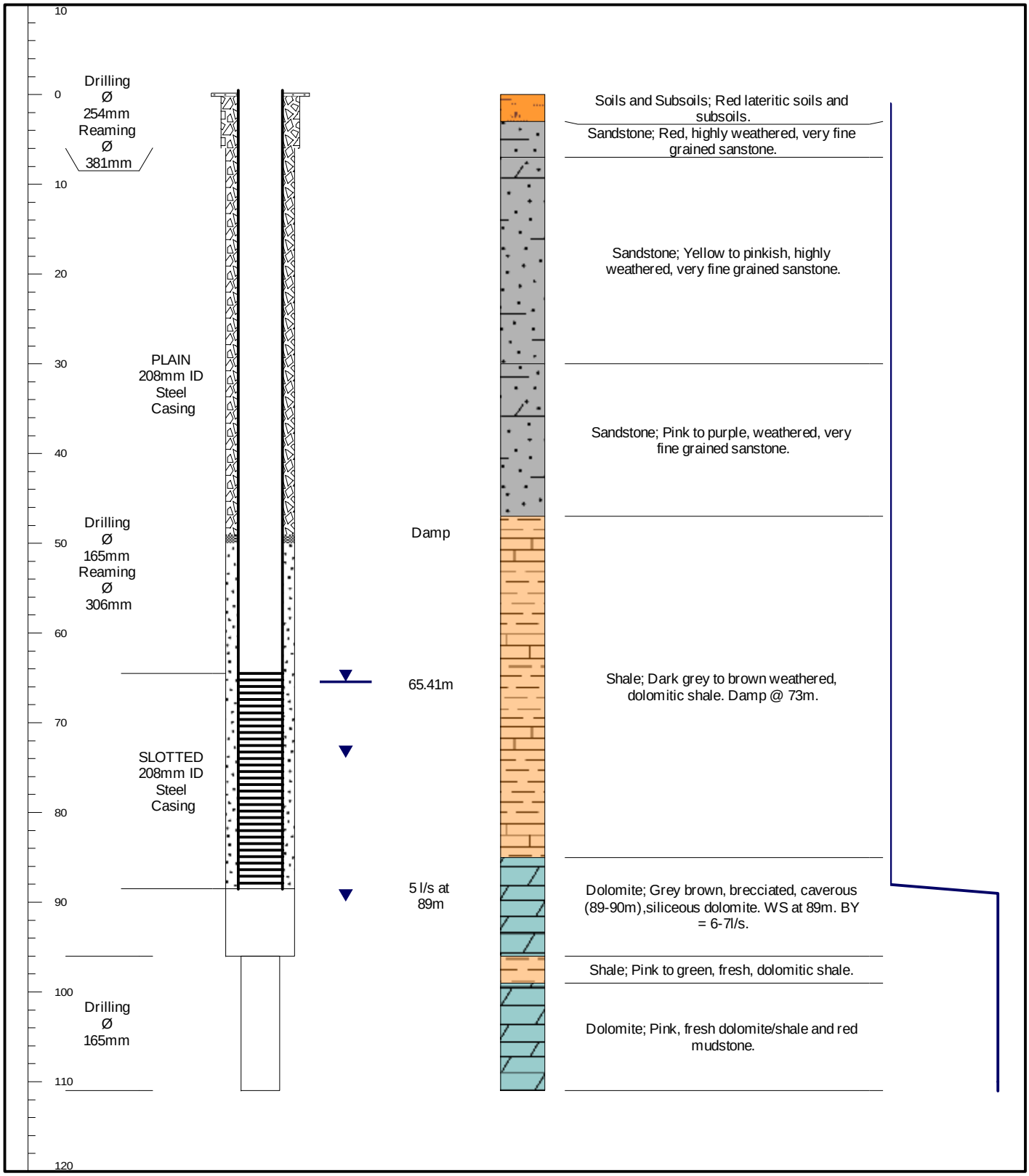


TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	8/12/06	**Collar Height (magl):**	0.4	Borehole No.	
Y co-ordinate:	8831106	**Depth (mbgl):**	111	**SWL (mbgl):**	65.41	**TFWB02**	
X co-ordinate:	411439	**Casing Depth (m)**	89	**Blow Yield (l/s):**	7		
Elevation (mamsl):	1417						

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 2.00 4.00



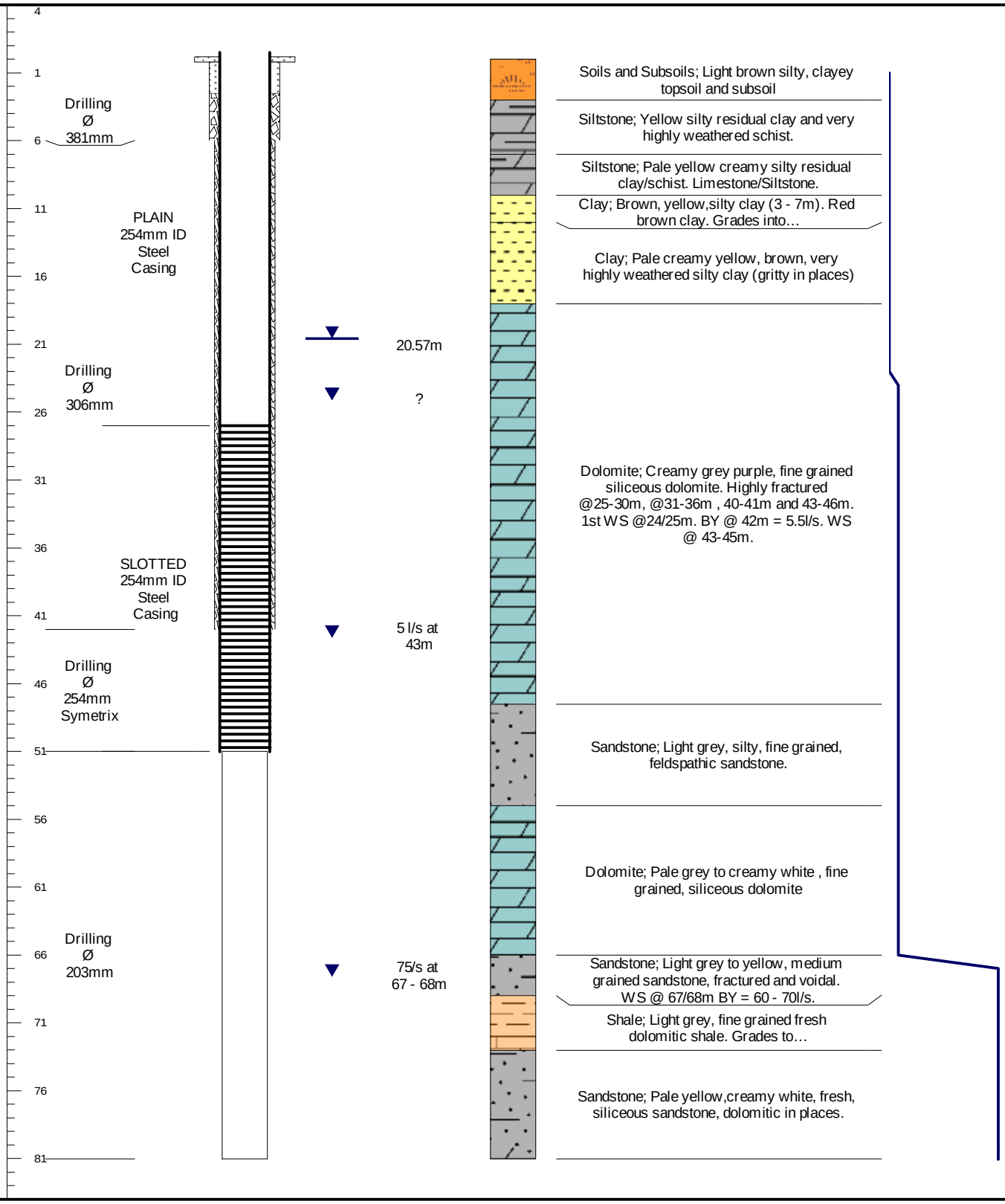
TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	8/13/06	**Collar Height (magl):**	0.18
Y co-ordinate:	8831551	**Depth (mbgl):**	81	**SWL (mbgl):**	20.57
X co-ordinate:	409430	**Casing Depth (m)**	52.1	**Blow Yield (l/s):**	>70.00
Elevation (mamsl):	1369				

Borehole No.
TFWB03A

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 20.00 40.00 60.00



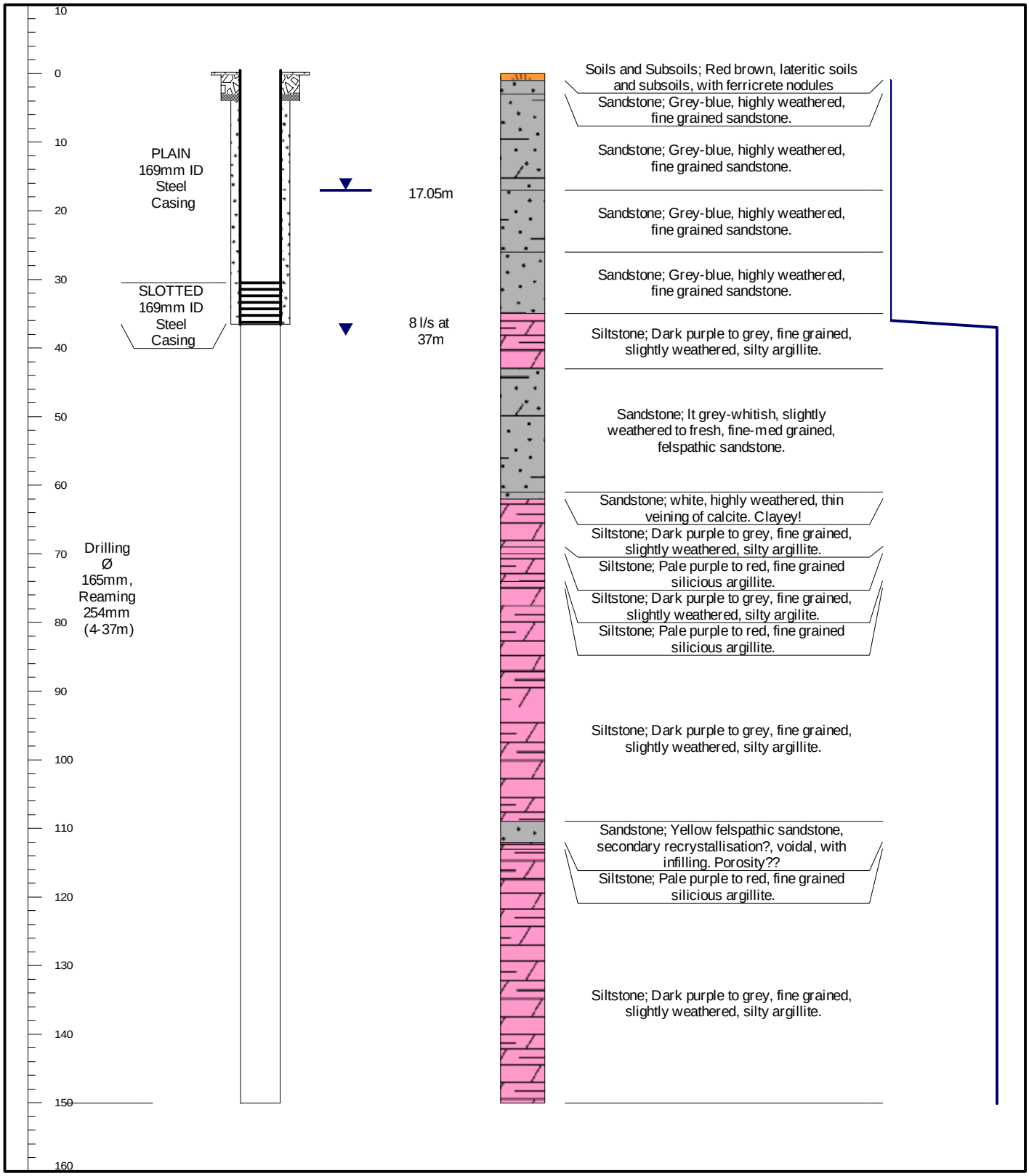
TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	9/5/06	**Collar Height (magl):**	0.17
Y co-ordinate:	8832994	**Depth (mbgl):**	150	**SWL (mbgl):**	17.05
X co-ordinate:	409746	**Casing Depth (m)**	36.5	**Blow Yield (l/s):**	10
Elevation (mamsl):	1353				

Borehole No.
TFWB04

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 2.00 4.00 6.00 8.00



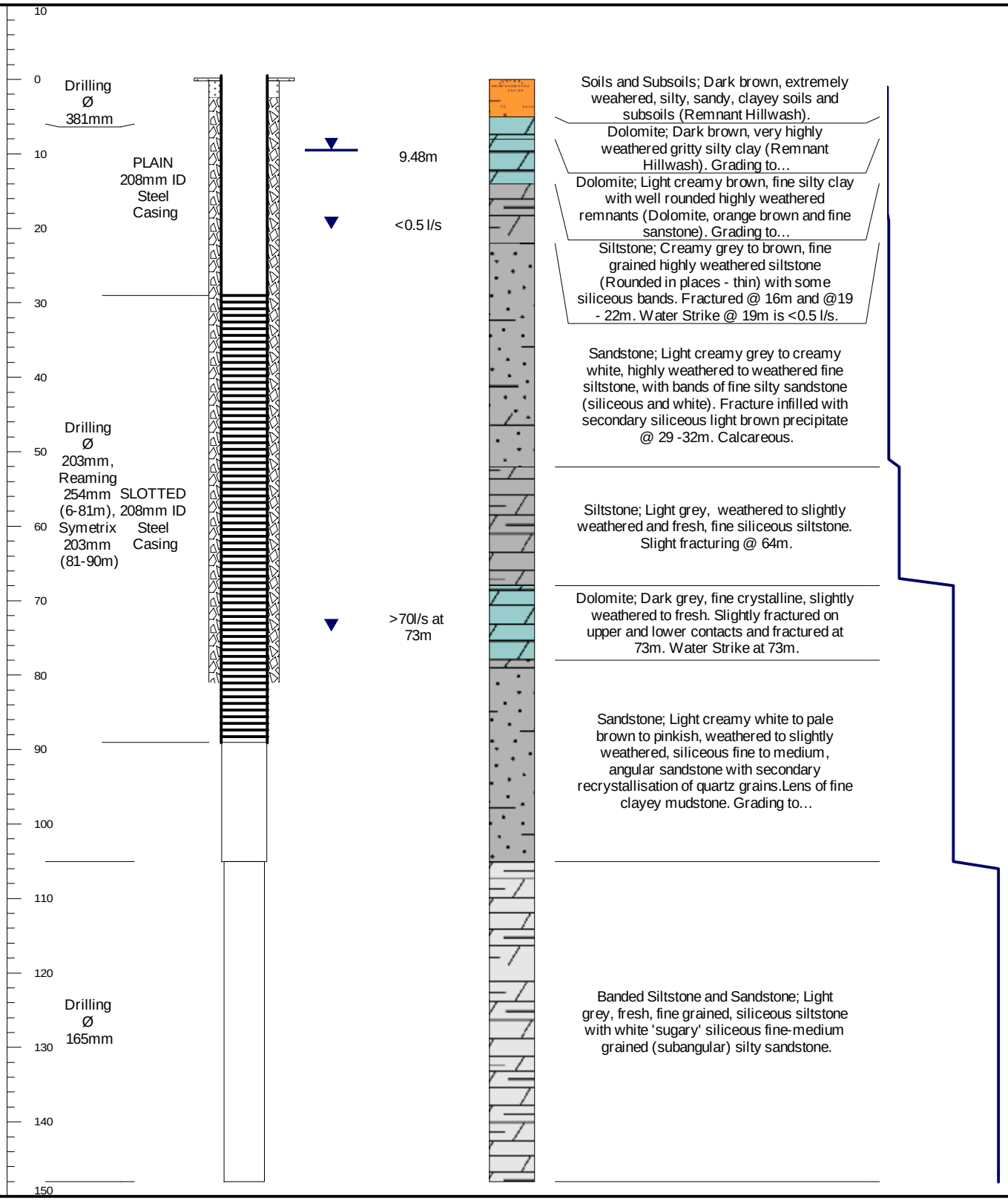
TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	10/14/06	**Collar Height (magl):**	0.27
Y co-ordinate:	8831503	**Depth (mbgl):**	148	**SWL (mbgl):**	9.48
X co-ordinate:	407027	**Casing Depth (m)**	90	**Blow Yield (l/s):**	>70.00
Elevation (mamsl):	1395				

Borehole No. TFWB05

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 20.00 40.00



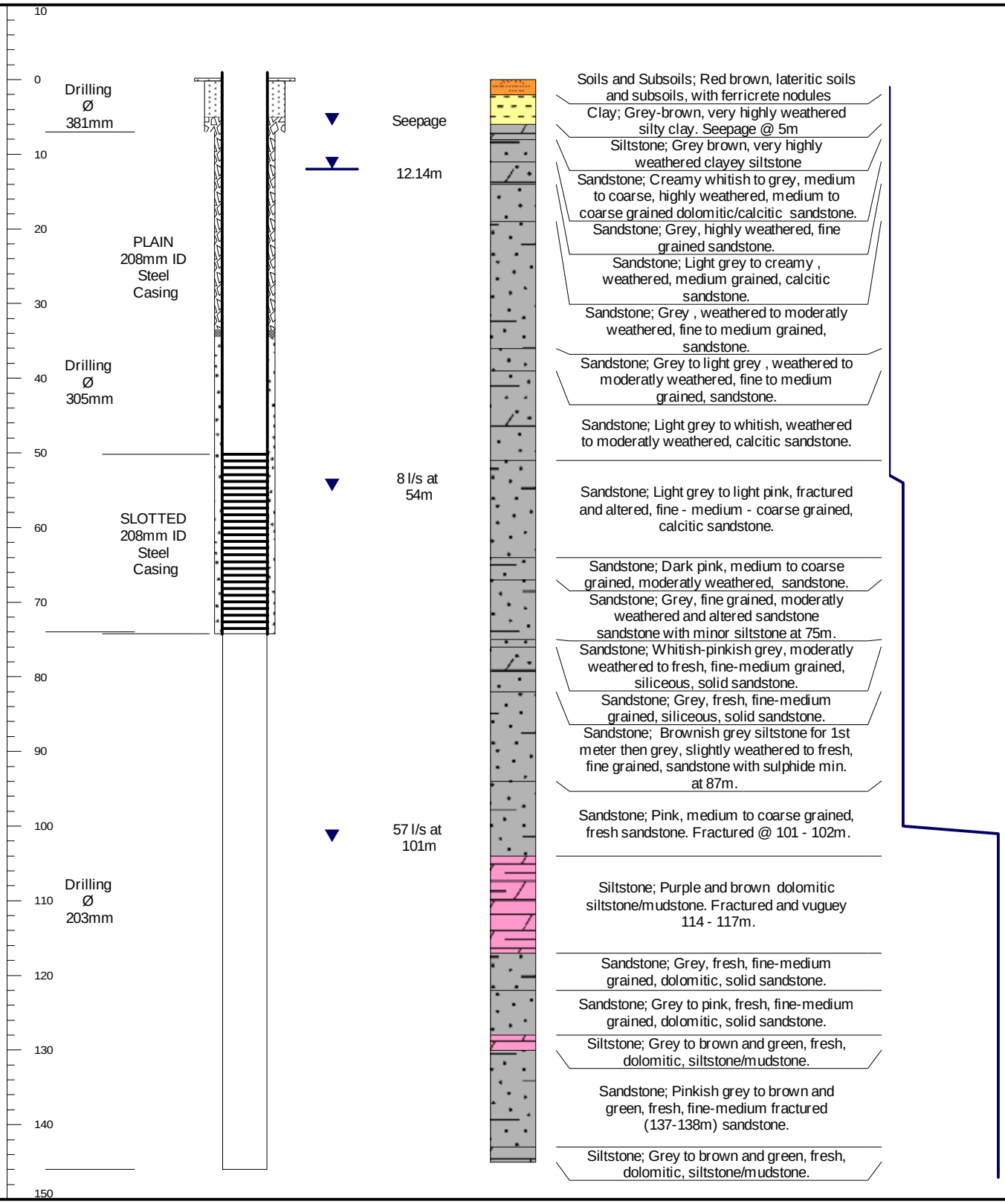
TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	8/17/06	**Collar Height (magl):**	0.44
Y co-ordinate:	8831243.83389	**Depth (mbgl):**	150	**SWL (mbgl):**	12.14
X co-ordinate:	412380.42821	**Casing Depth (m)**	75	**Blow Yield (l/s):**	65
Elevation (mamsl):	1382				

Borehole No.
TFWB06A

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 20.00 40.00 60.00



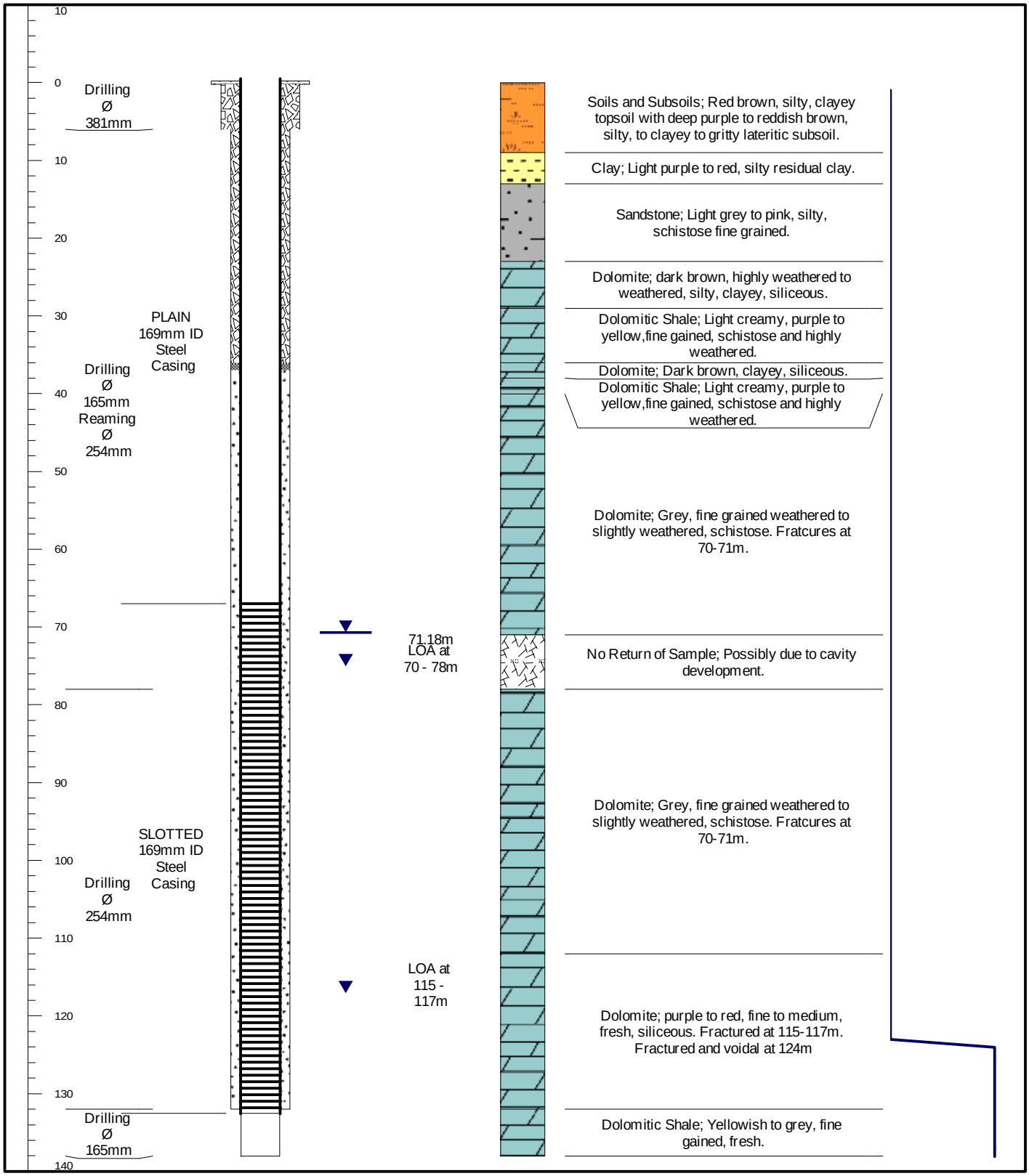
TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	8/19/06	**Collar Height (magl):**	0.37
Y co-ordinate:	8829328	**Depth (mbgl):**	138	**SWL (mbgl):**	71.18
X co-ordinate:	410808	**Casing Depth (m)**	132.5	**Blow Yield (l/s):**	15
Elevation (mamsl):	1391				

Borehole No.
TFWB08

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 5.00 10.00 15.00



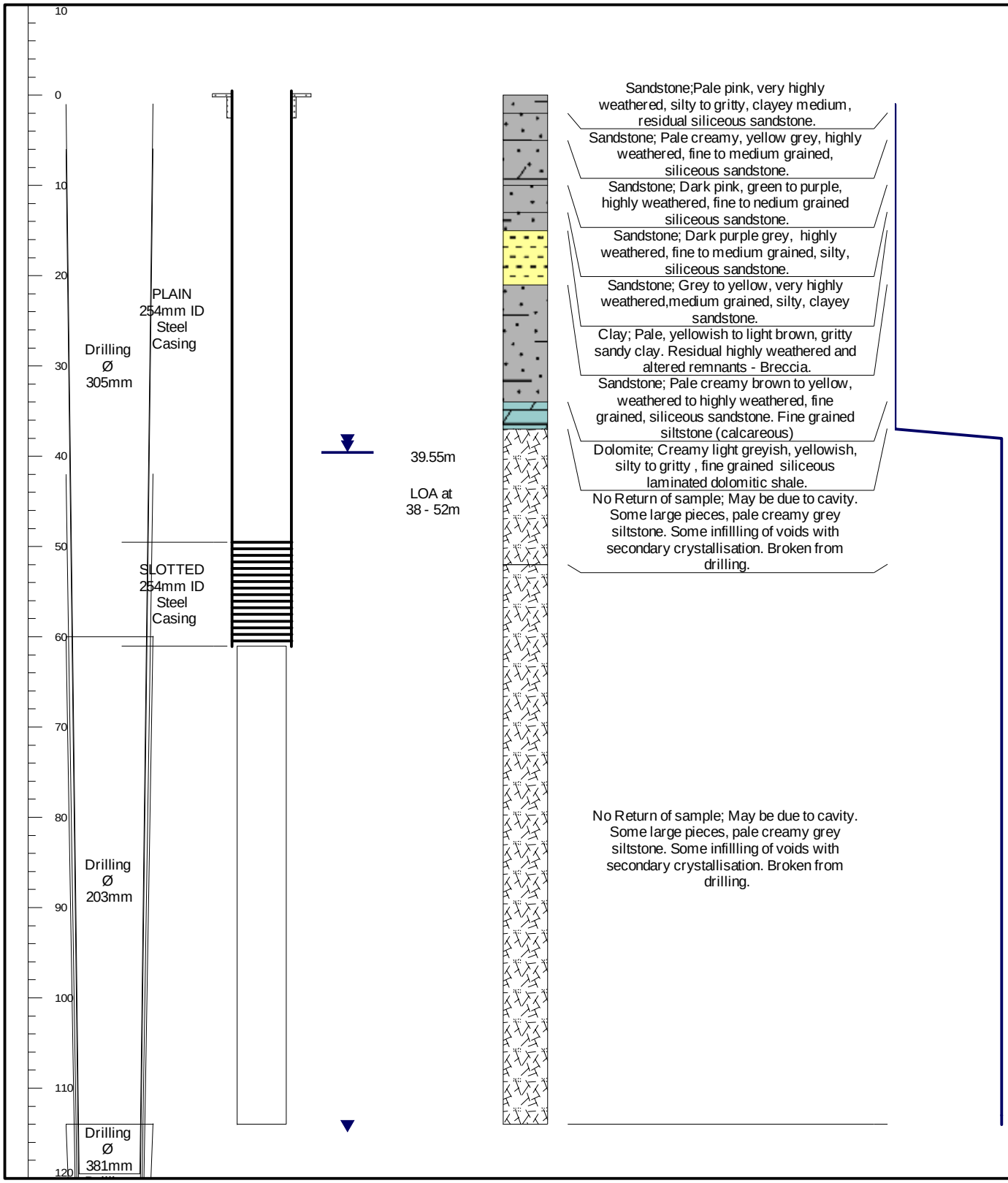
TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	8/20/06	**Collar Height (magl):**	0.14
Y co-ordinate:	8828539	**Depth (mbgl):**	114	**SWL (mbgl):**	39.55
X co-ordinate:	410181	**Casing Depth (m)**	60	**Blow Yield (l/s):**	>70.00
Elevation (mamsl):	1353				

Borehole No.
TFWB09

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 10.00 20.00 30.00 40.00



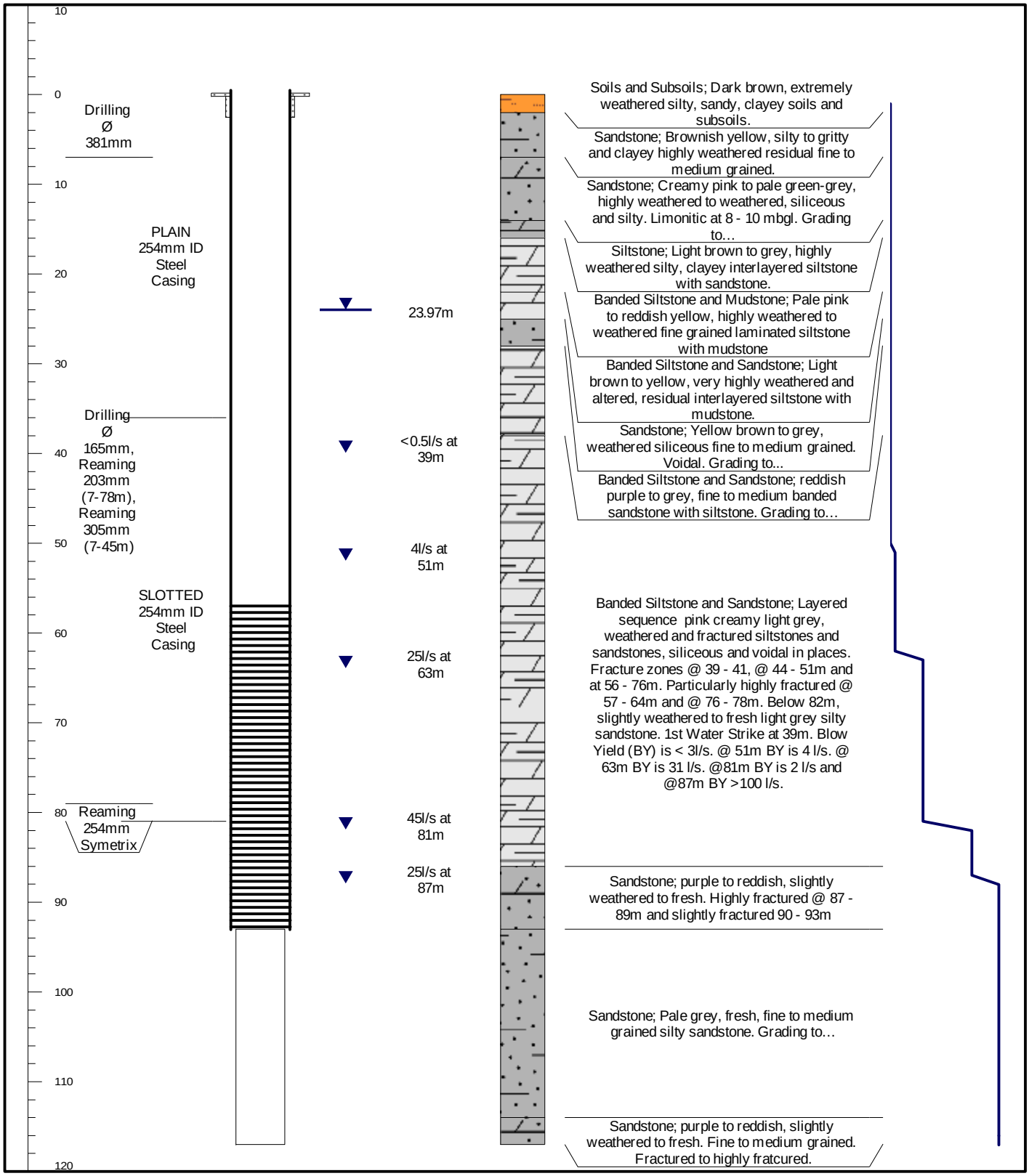
TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	8/21/06	**Collar Height (magl):**	0.3
Y co-ordinate:	8827958	**Depth (mbgl):**	117	**SWL (mbgl):**	23.97
X co-ordinate:	409763	**Casing Depth (m)**	93	**Blow Yield (l/s):**	>70.00
Elevation (mamsl):					

Borehole No. TFWB10

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 25.00 50.00 75.00 100.00

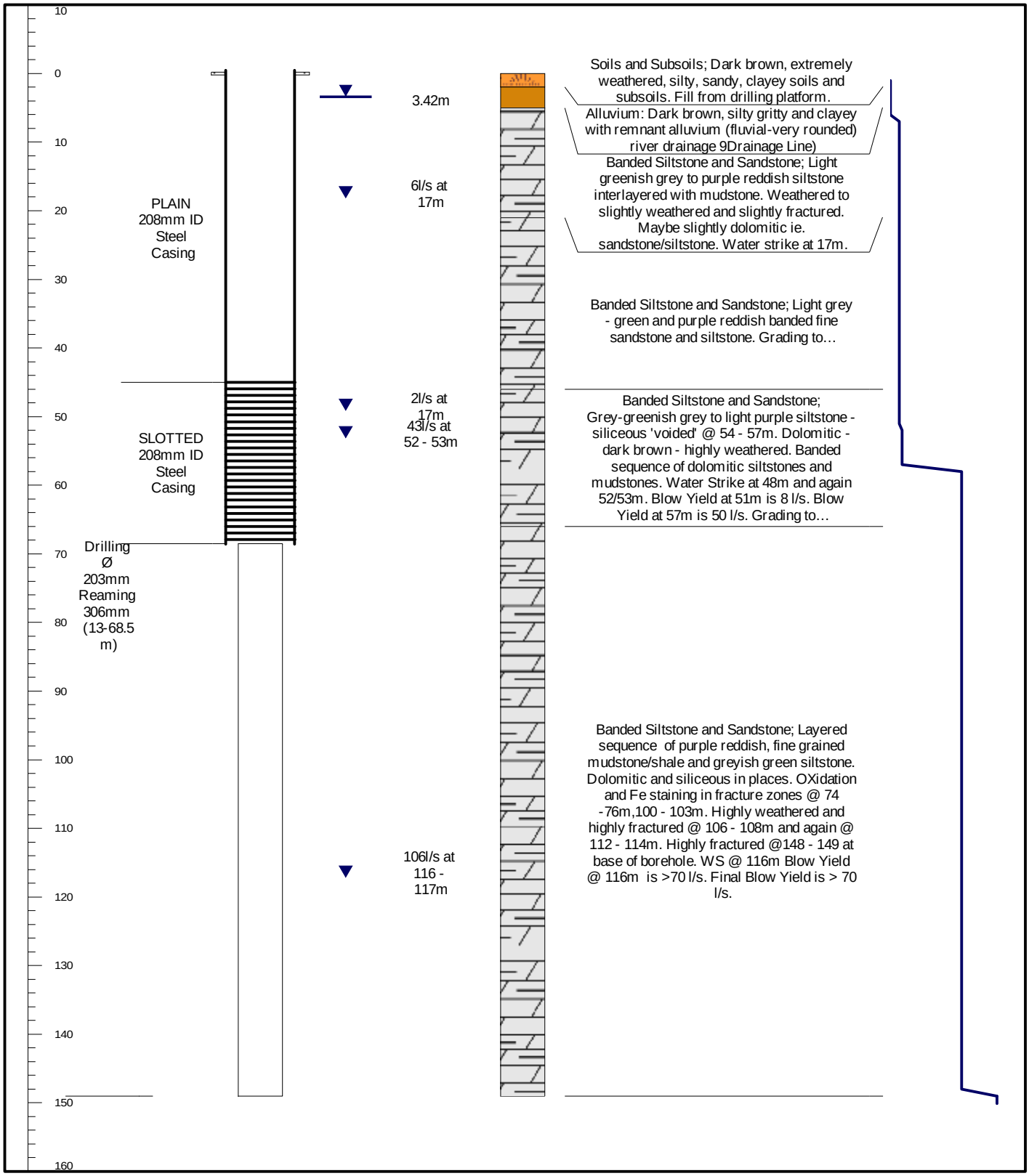


TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

Location:	UTM 35 L	**Date drilled:**	10/11/06	**Collar Height (magl):**	0.52	Borehole No.	
Y co-ordinate:	8827416	**Depth (mbgl):**	150	**SWL (mbgl):**	3.42		
X co-ordinate:	410953	**Casing Depth (m)**	69	**Blow Yield (l/s):**	>70.00	**TFWB12**	
Elevation (mamsl):	1308						

Depth (mbgl)	Drilling Diam (mm)	Borehole Construction Description & Log	SWL, Water Strikes and Blow Yields	Lithological Log and Description	Blow Yield (l/s) 0.00 20.00 40.00 60.00 80.00



TENKE FUNGURUME
HYDROGEOLOGICAL STUDY

Golder Associates

ATTACHMENT 2

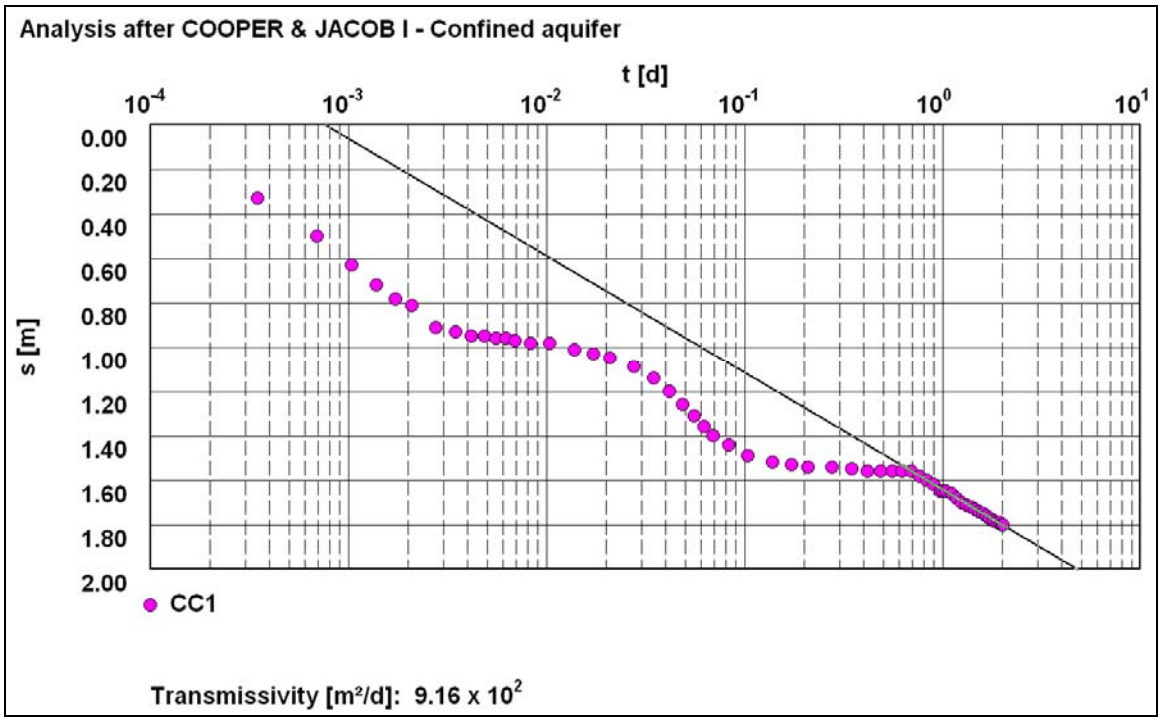
GROUNDWATER LEVEL MEASUREMENTS

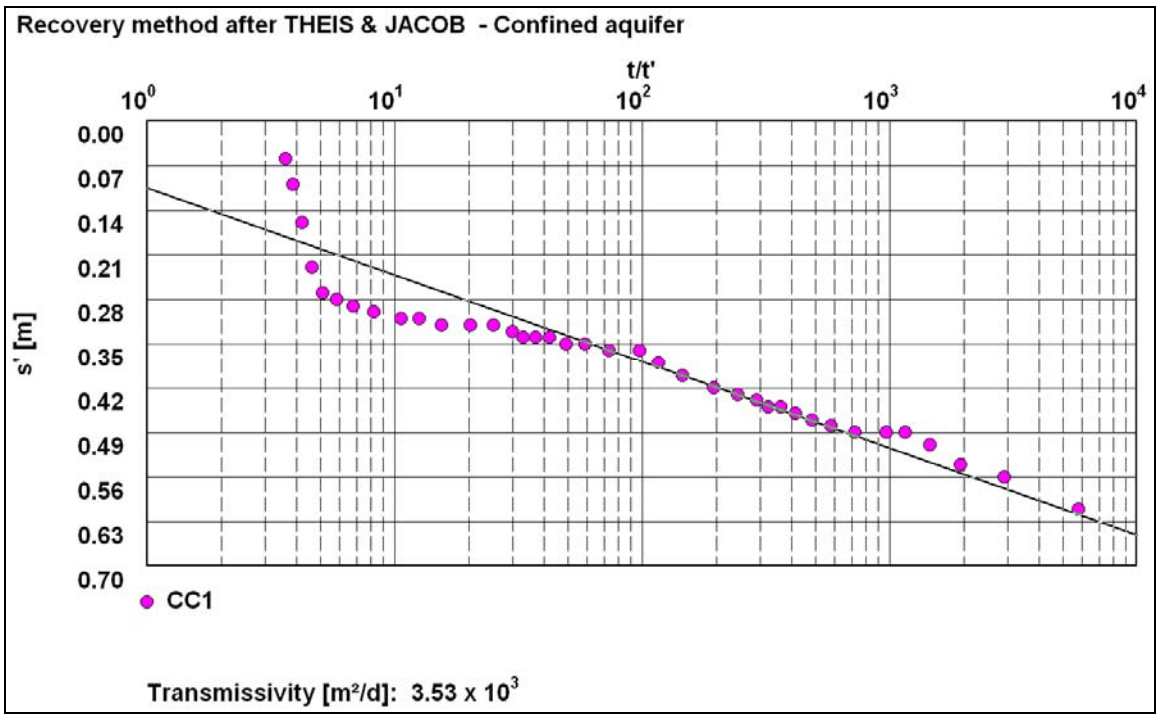
Table 1 Borehole numbers, X, Y and Z-co-ordinates of boreholes and calculated water level elevations for each of the boreholes

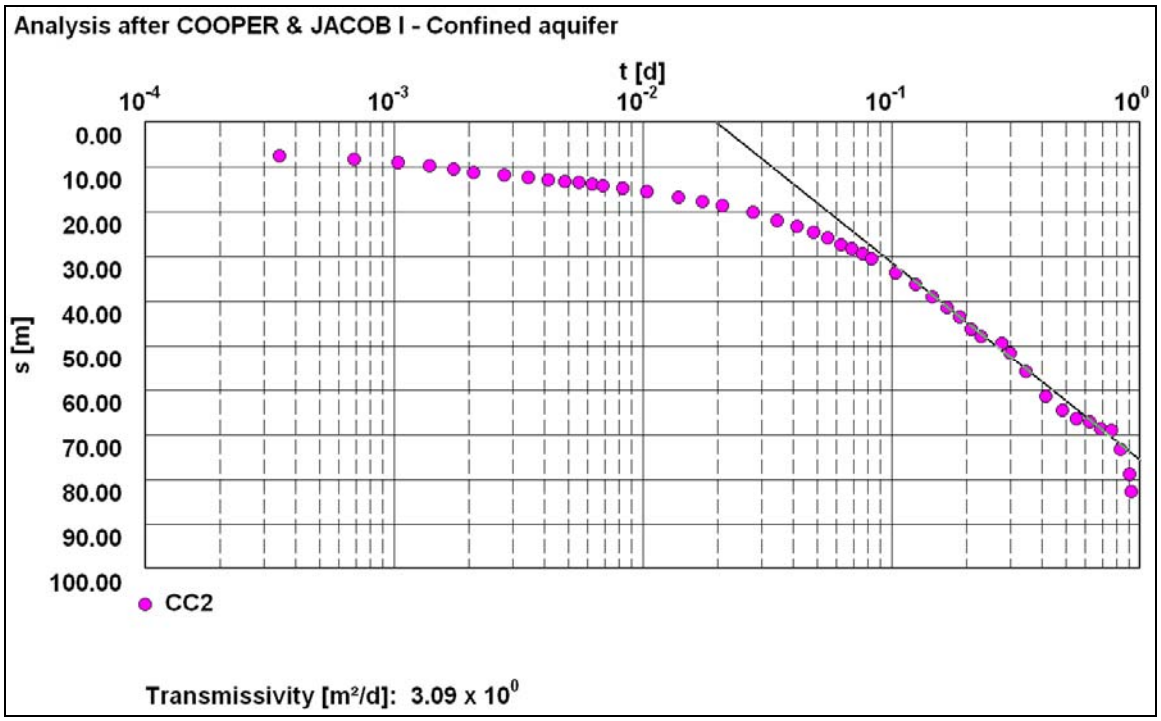
Borehole No.	UTM Co-ordinate X Zone 35S	UTM Co-ordinate Y Zone 35S	Static Water Level (mbgl)	Interpolated Z (mamsl)	Calculated Static Water Level Elevation (mamsl)
TFM1	424025.00	8826130.00	10.58	1172.55	1161.97
TFM3	423875.00	8827330.00	6.50	1187.29	1180.79
TFWB12	410953.00	8827416.00	3.24	1307.51	1304.27
TFWB10	409763.00	8827958.00	23.47	1314.14	1290.67
TFWB09	410181.00	8828539.00	39.35	1353.32	1313.97
TFWB08	410808.00	8829328.00	70.68	1391.11	1320.43
TFM4	409610.00	8829542.00	4.49	1357.90	1353.41
TFEB10	406709.00	8829959.00	39.76	1388.52	1348.76
TFEB5	408296.00	8830211.00	49.77	1405.31	1355.54
TFWB01A	411200.00	8830654.00	84.24	1429.12	1344.88
THG3	407725.00	8830658.00	50.40	1408.55	1358.15
TFWB02	411435.00	8831106.00	65.41	1417.49	1352.08
TFM5	408626.00	8831216.00	26.42	1385.06	1358.64
TFWB06A	412439.00	8831346.00	12.00	1383.80	1371.80
TFEB06	407199.00	8831706.00	5.53	1390.19	1384.66
TFM6	409476.00	8831460.00	22.16	1369.88	1347.72
TFWB05	407207.00	8831503.00	10.65	1394.84	1384.19
TFWB3A	409437.00	8831564.00	18.89	1369.78	1350.89
TFEB07	408508.00	8831970.00	30.25	1370.31	1340.06
TFWB04	409746.00	8832994.00	16.94	1352.69	1335.75
TFWB03A	409437.00	8831564.00	18.89	1369.78	1350.89
TFWB2	411435.00	8831106.00	65.41	1417.49	1352.08
TFEB08	409032.00	8832439.00	37.74	1365.79	1328.05
TFEB12	410465.00	8831664.00	18.39	1376.80	1358.41
TFEB2	411782.00	8831736.00	12.20	1395.87	1383.67

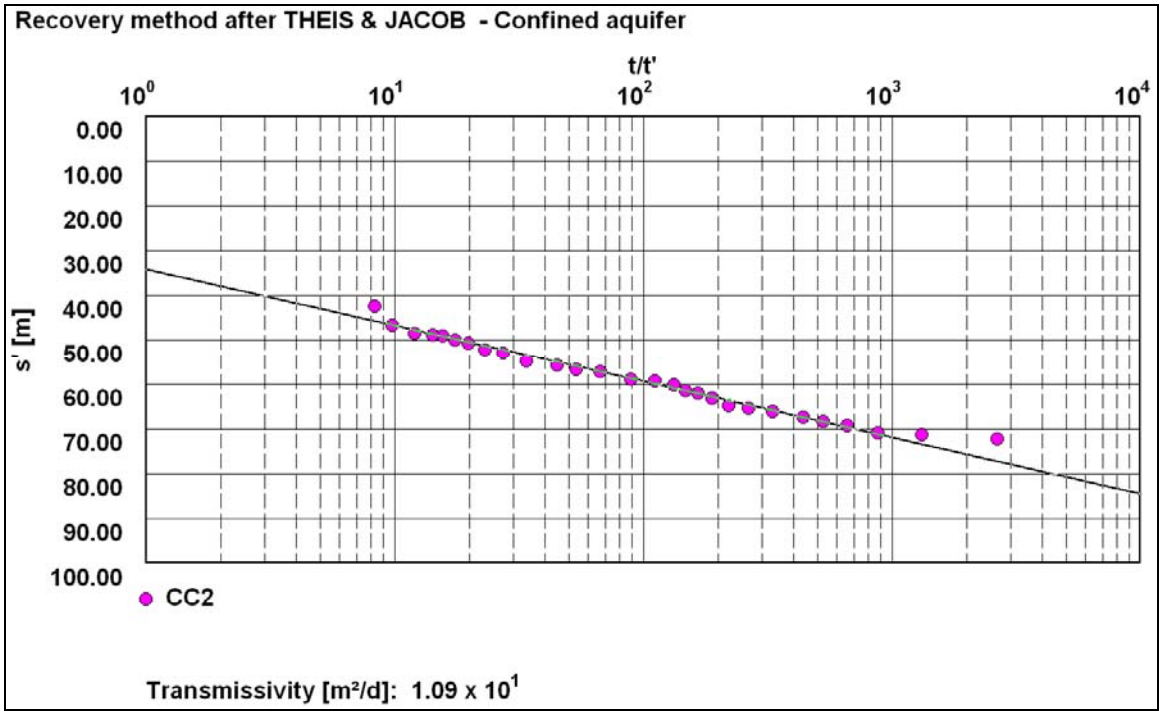
ATTACHMENT 3

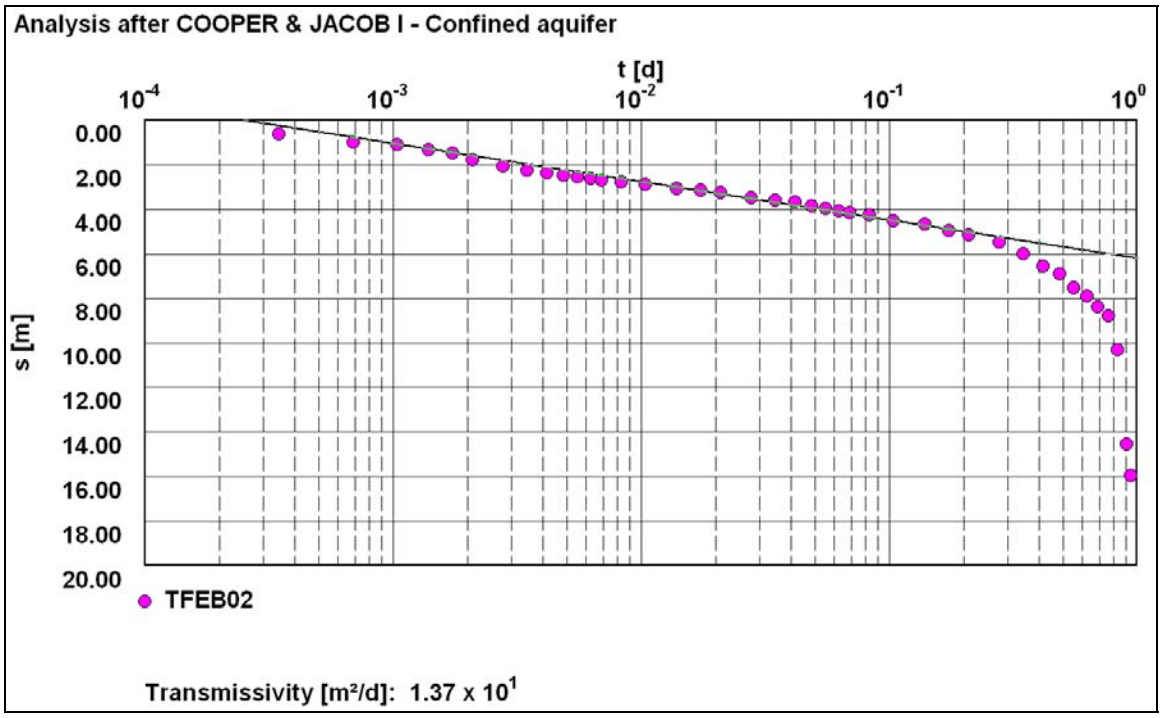
PUMPING TEST HYDROGRAPHS

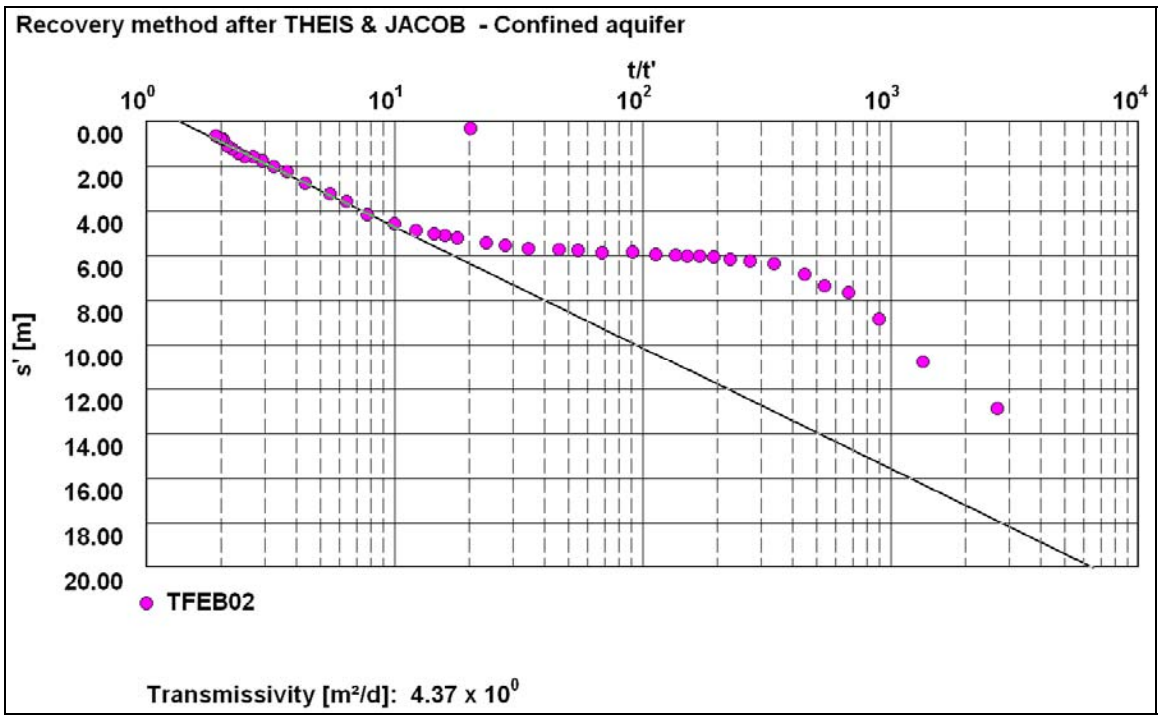

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
101
s [m]
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
CC1
Transmissivity [m²/d]: 9.16 x 10²

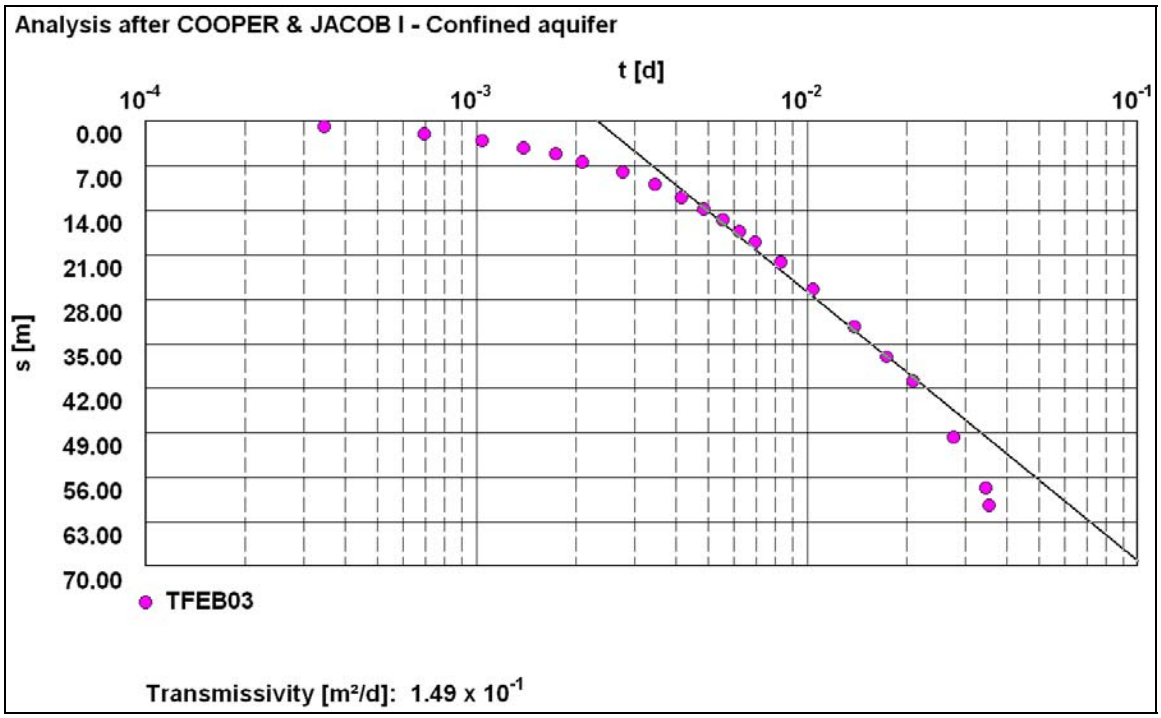

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
100
101
102
103
104
s' [m]
0.00
0.07
0.14
0.21
0.28
0.35
0.42
0.49
0.56
0.63
0.70
CC1
Transmissivity [m²/d]: 3.53 x 10³

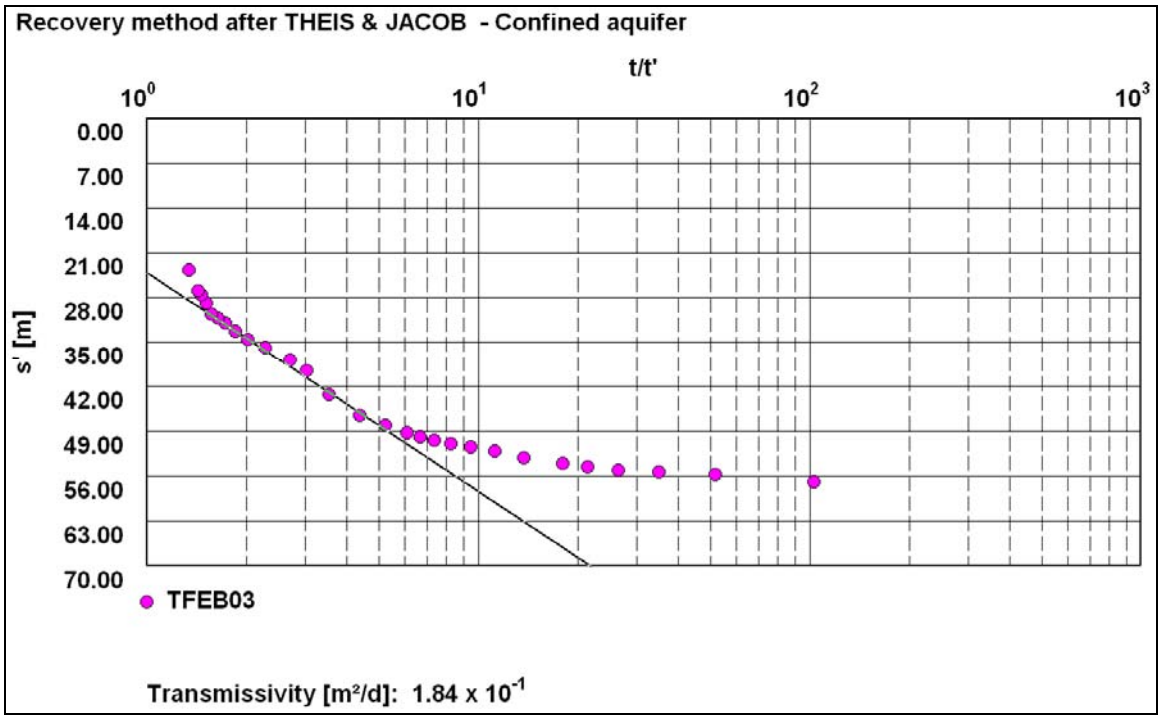

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
s [m]
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
CC2
Transmissivity [m²/d]: 3.09 x 10^0

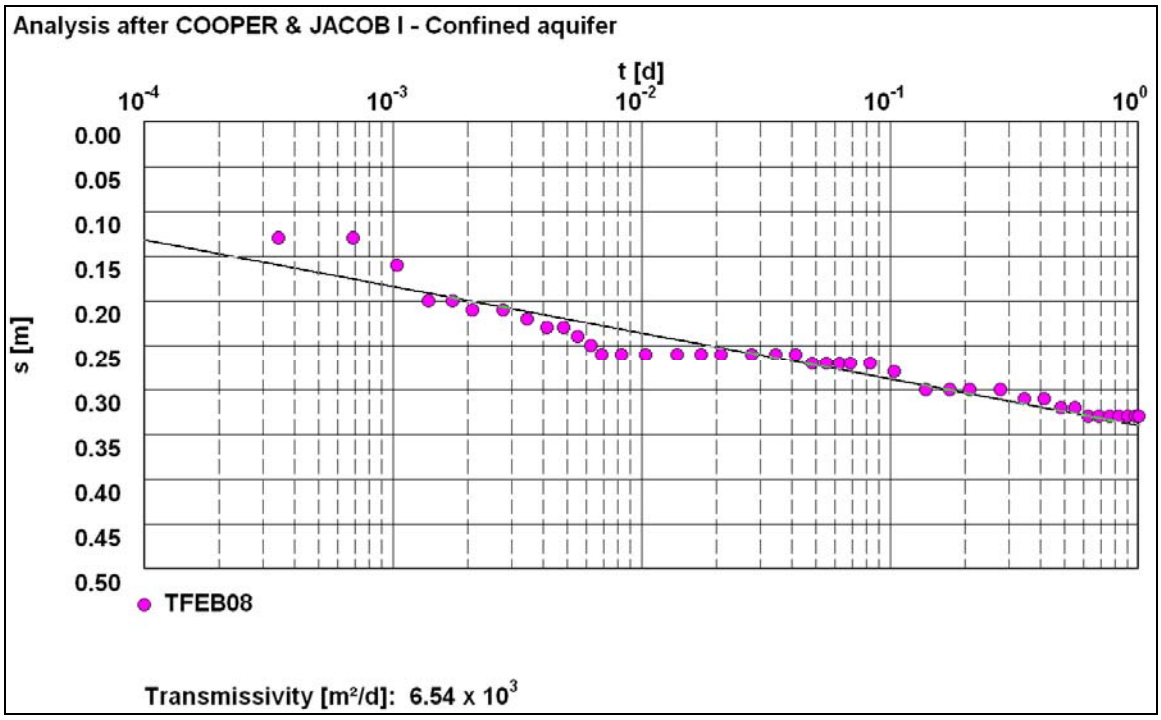

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
100
101
102
103
104
s' [m]
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
CC2
Transmissivity [m²/d]: 1.09 x 10^1

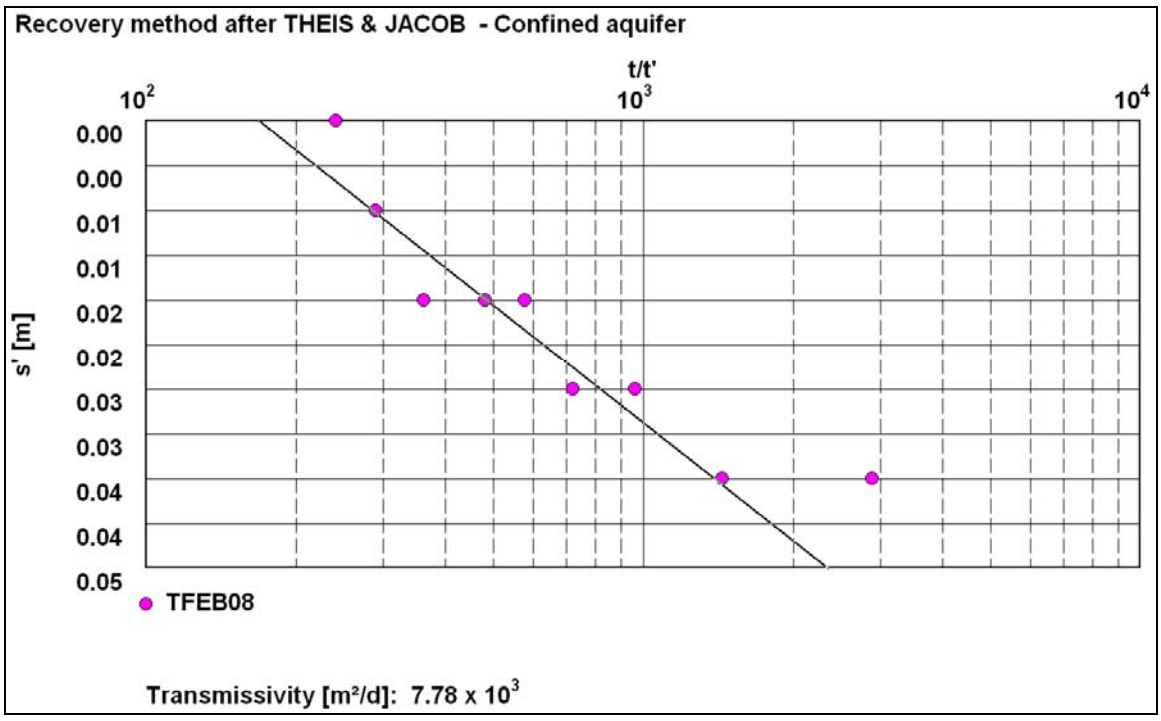

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
s [m]
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
TFEB02
Transmissivity [m²/d]: 1.37 x 10¹

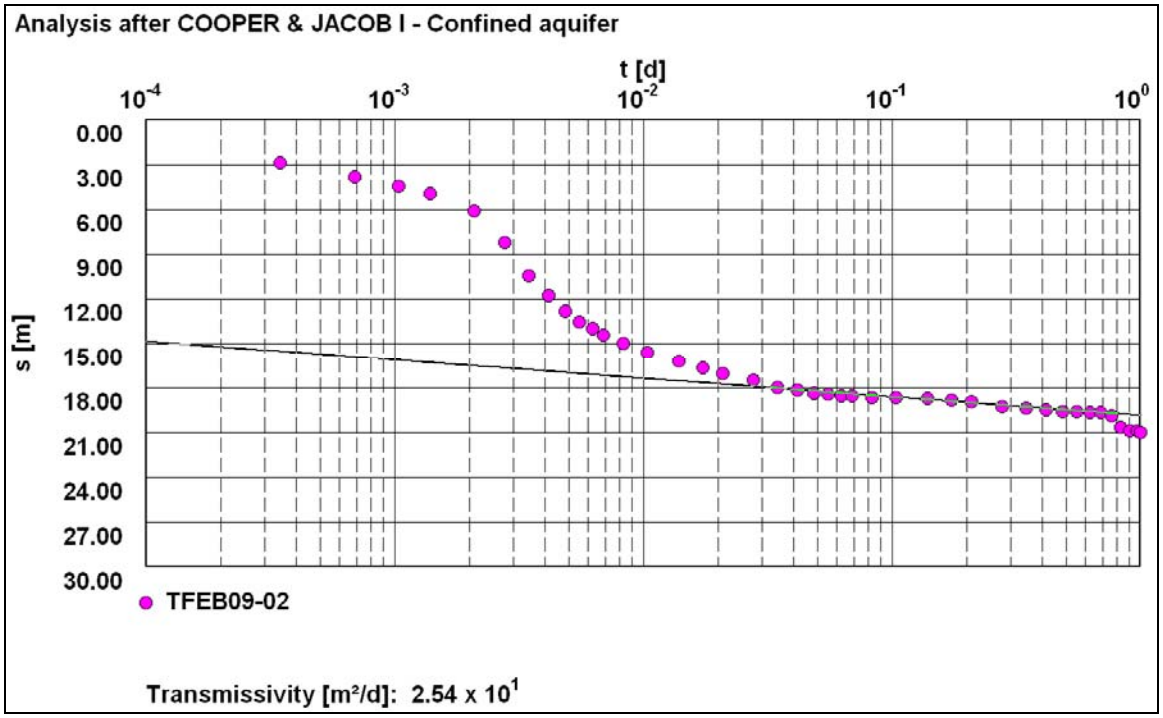

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
100
101
102
103
104
s' [m]
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
TFEB02
Transmissivity [m²/d]: 4.37 x 10⁰

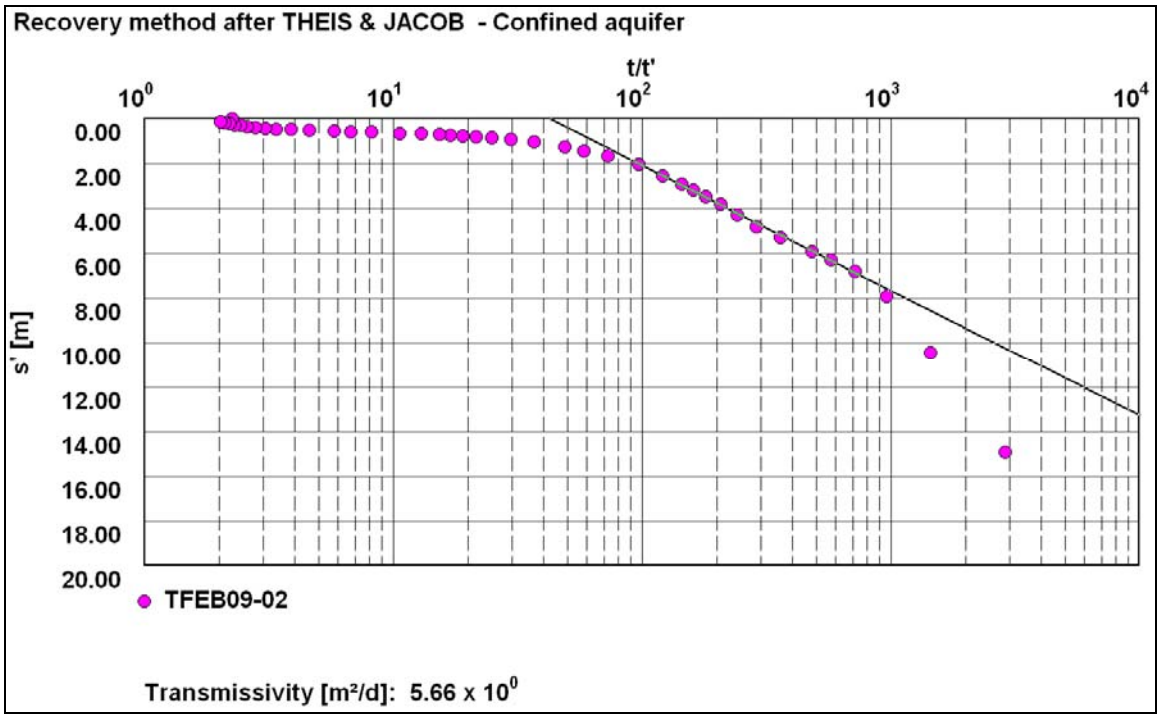

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
0.00
7.00
14.00
21.00
28.00
35.00
42.00
49.00
56.00
63.00
70.00
s [m]
TFEB03
Transmissivity [m²/d]: 1.49 x 10-1

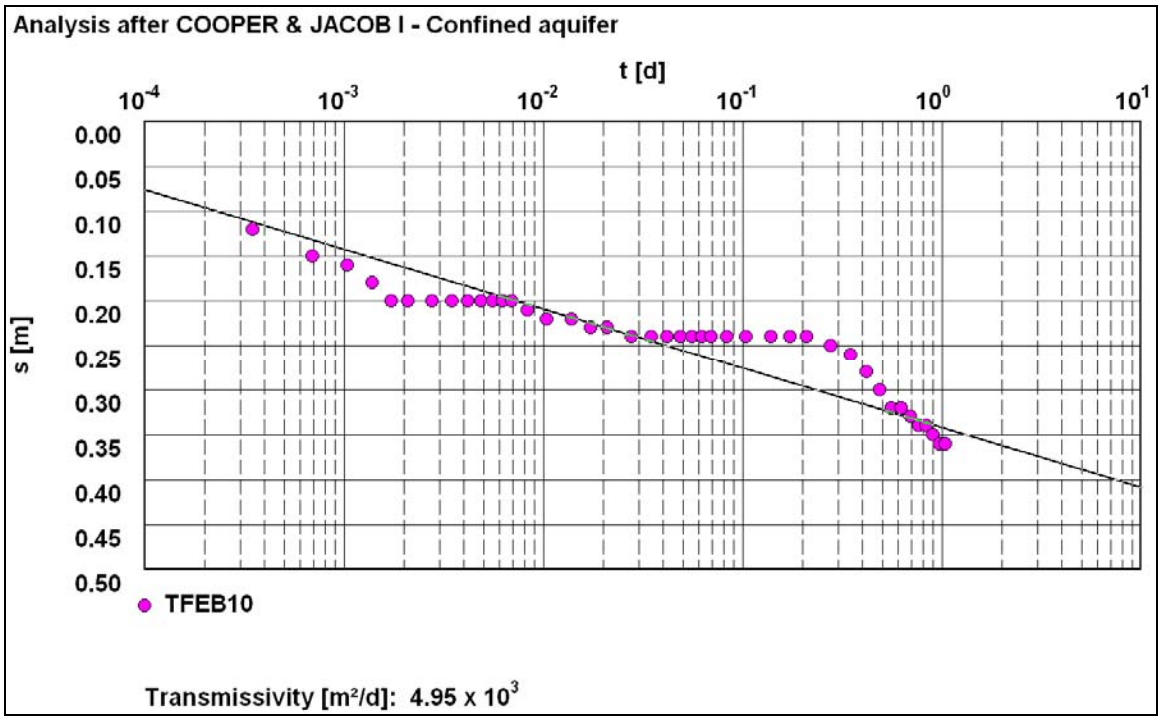

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
100
101
102
103
0.00
7.00
14.00
21.00
28.00
35.00
42.00
49.00
56.00
63.00
70.00
s' [m]
TFEB03
Transmissivity [m²/d]: 1.84 x 10-1

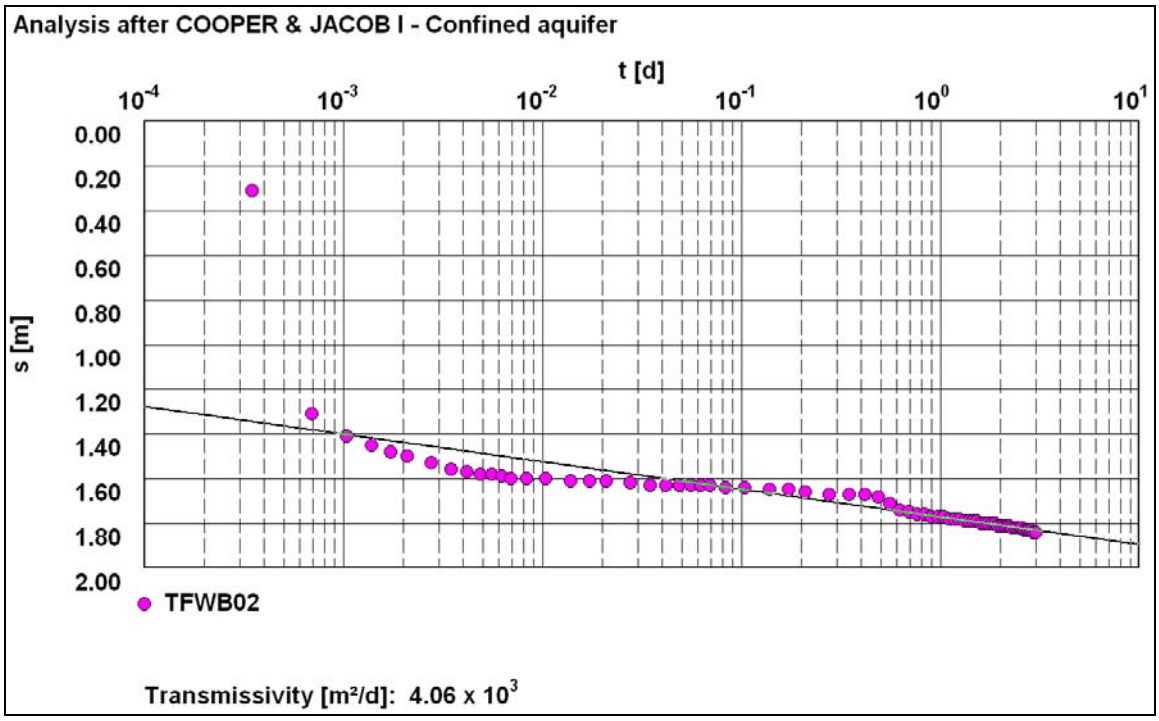

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
s [m]
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
TFEB08
Transmissivity [m²/d]: 6.54 x 10³

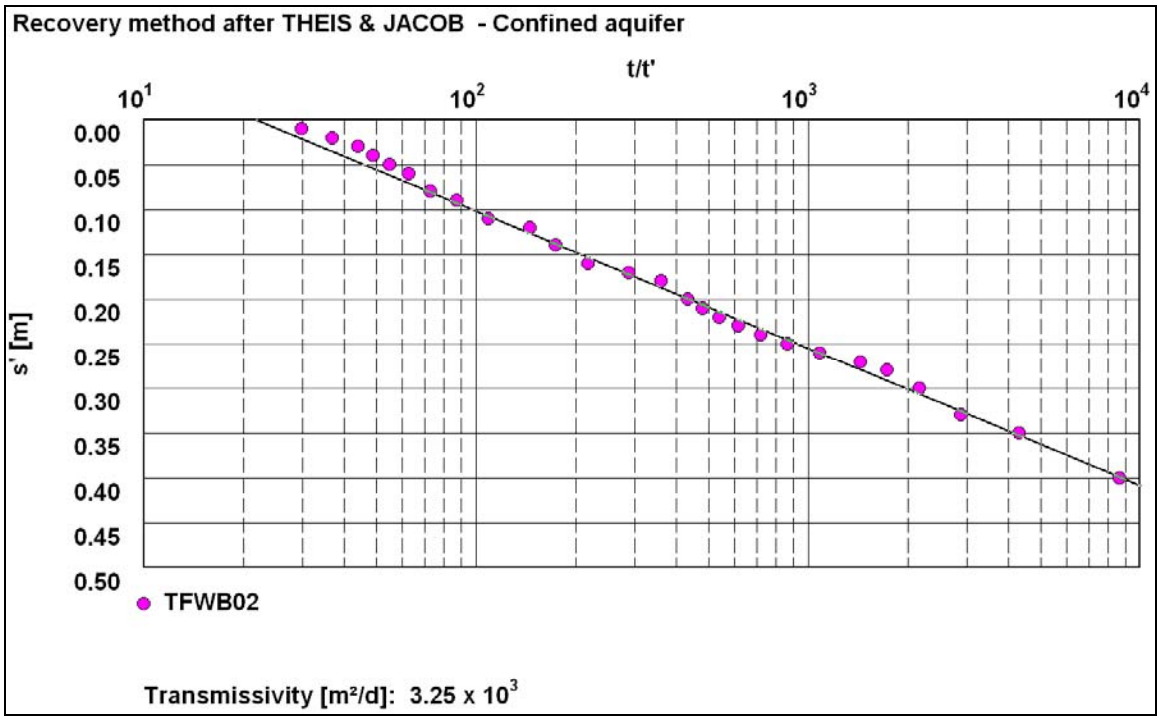

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
10²
10³
10⁴
s' [m]
0.00
0.00
0.01
0.01
0.02
0.02
0.03
0.03
0.04
0.04
0.05
TFEB08
Transmissivity [m²/d]: 7.78 x 10³

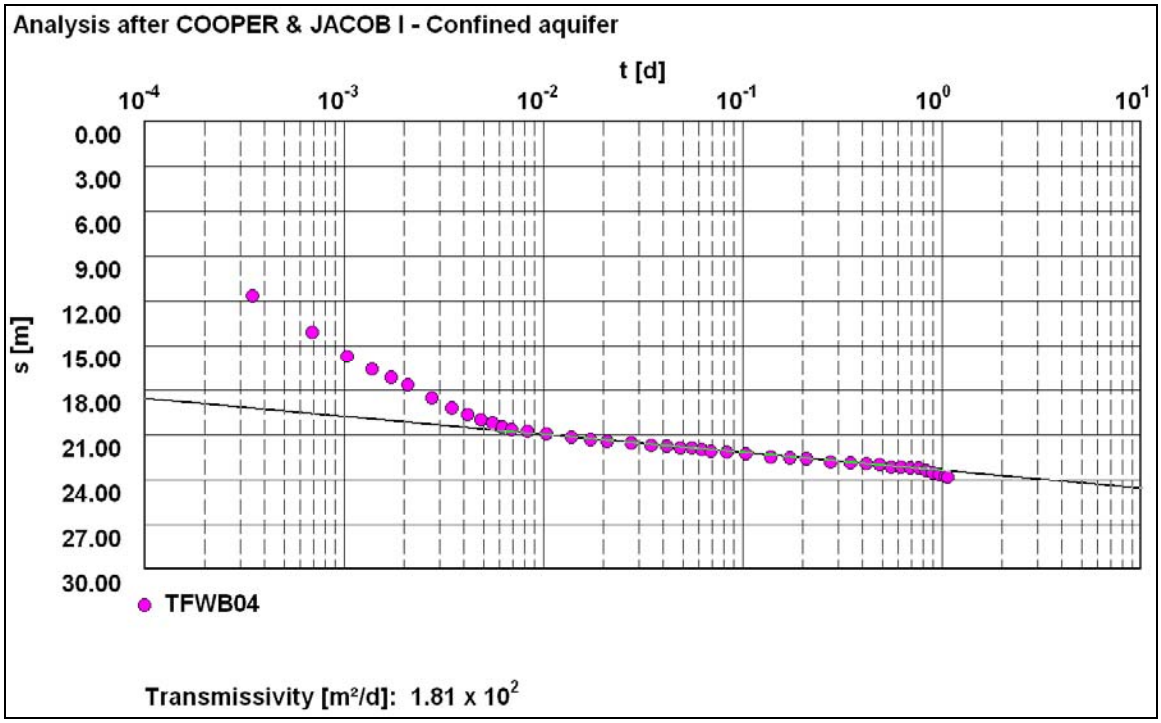

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
s [m]
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
TFEB09-02
Transmissivity [m²/d]: 2.54 x 10¹

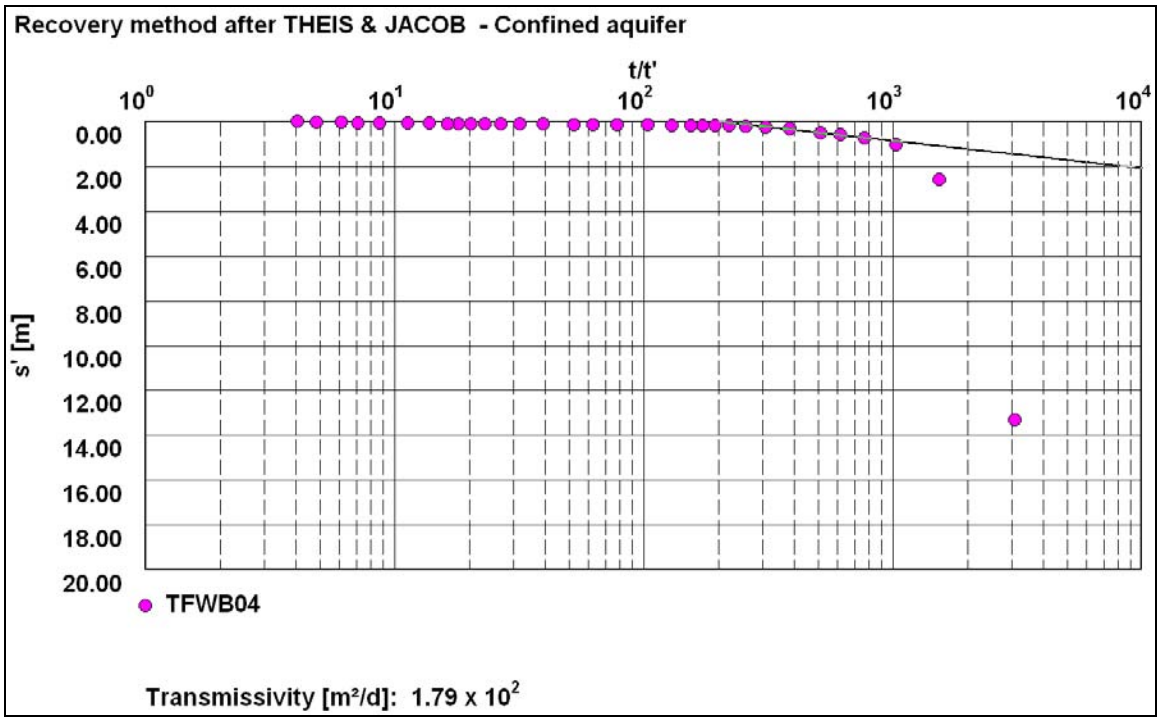

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
100
101
102
103
104
s' [m]
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
TFEB09-02
Transmissivity [m²/d]: 5.66 x 10⁰

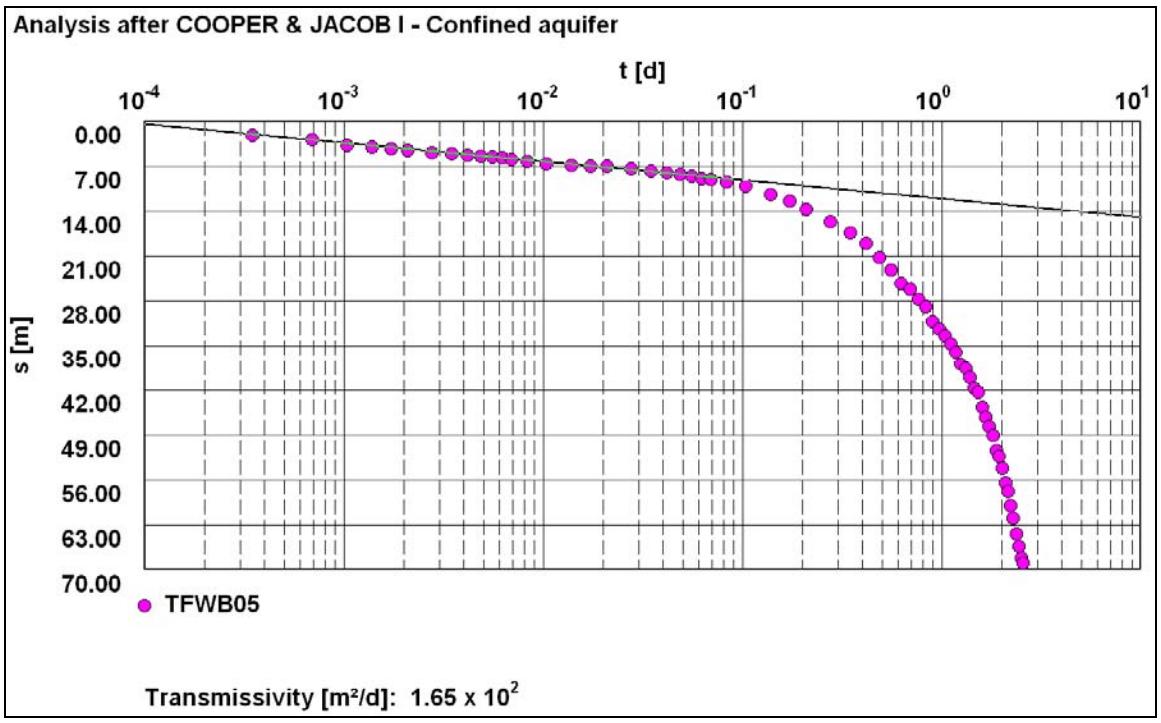

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
101
s [m]
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
TFEB10
Transmissivity [m²/d]: 4.95 x 10³

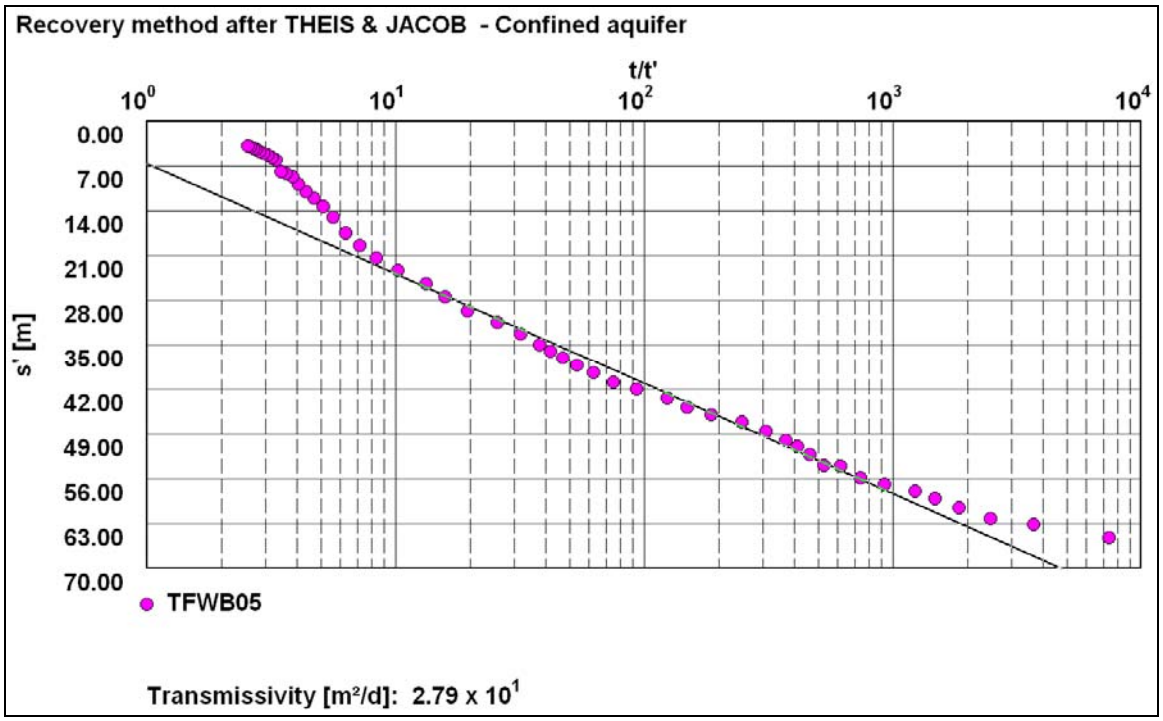

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
101
s [m]
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
TFWB02
Transmissivity [m²/d]: 4.06 x 10³

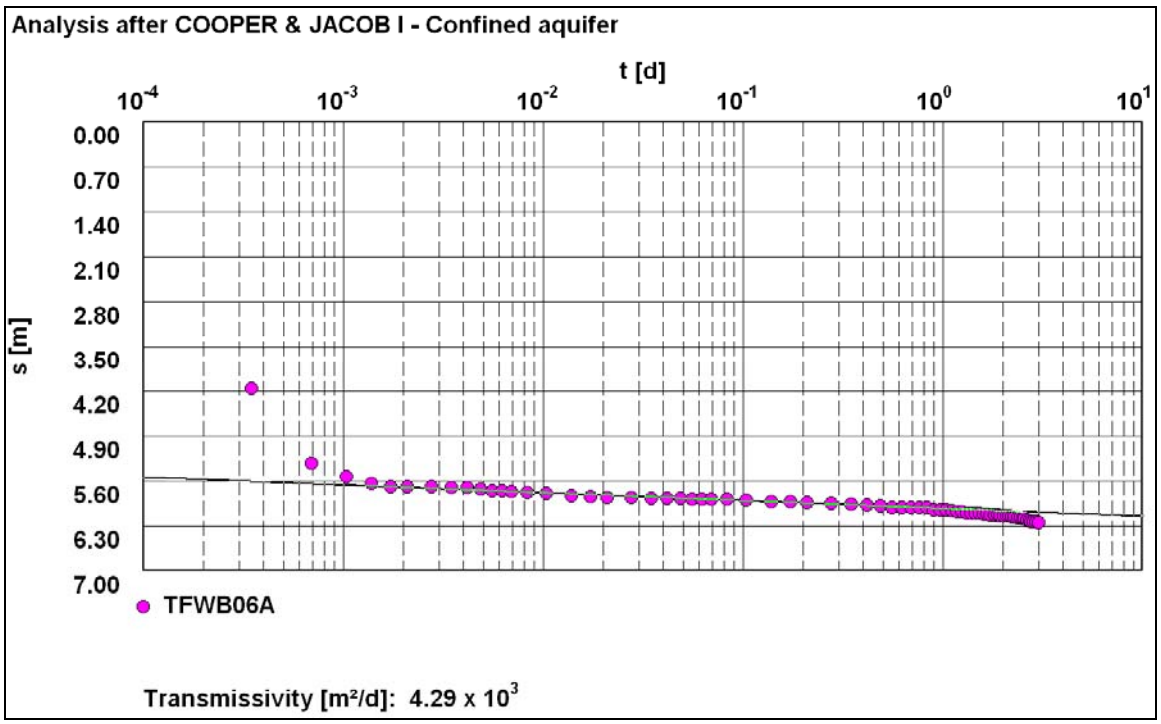

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
10^1
10^2
10^3
10^4
s' [m]
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
TFWB02
Transmissivity [m²/d]: 3.25 x 10^3

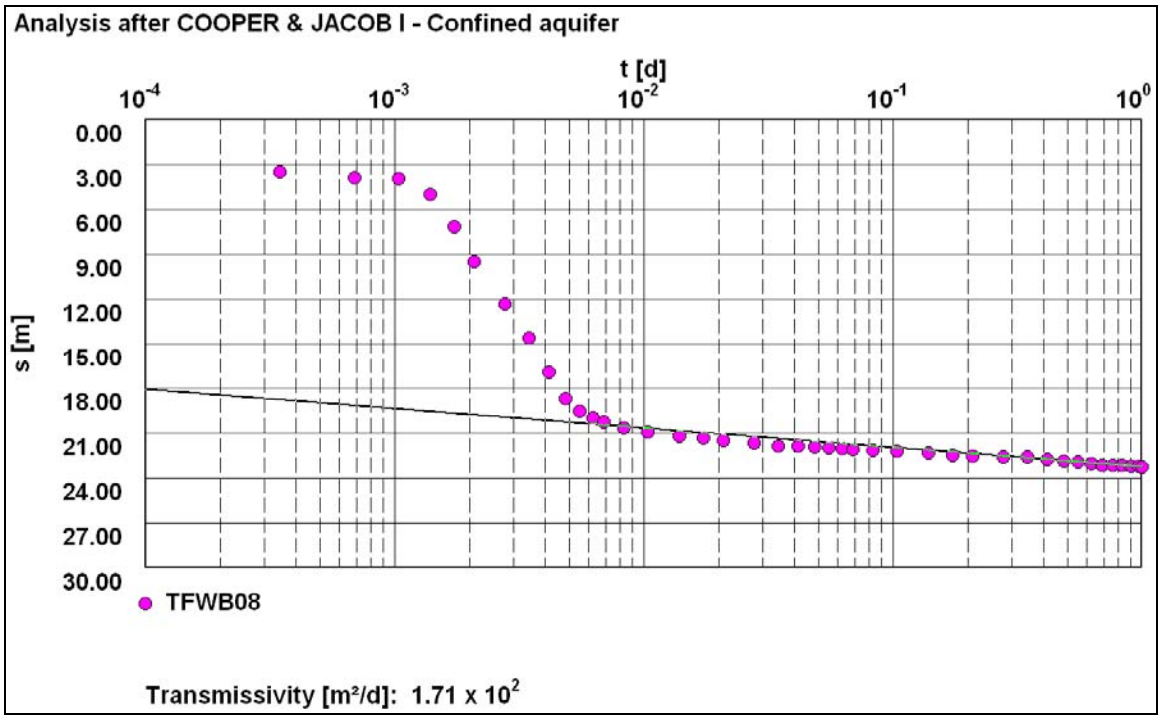

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10^-4
10^-3
10^-2
10^-1
10^0
10^1
s [m]
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
TFWB04
Transmissivity [m²/d]: 1.81 x 10^2

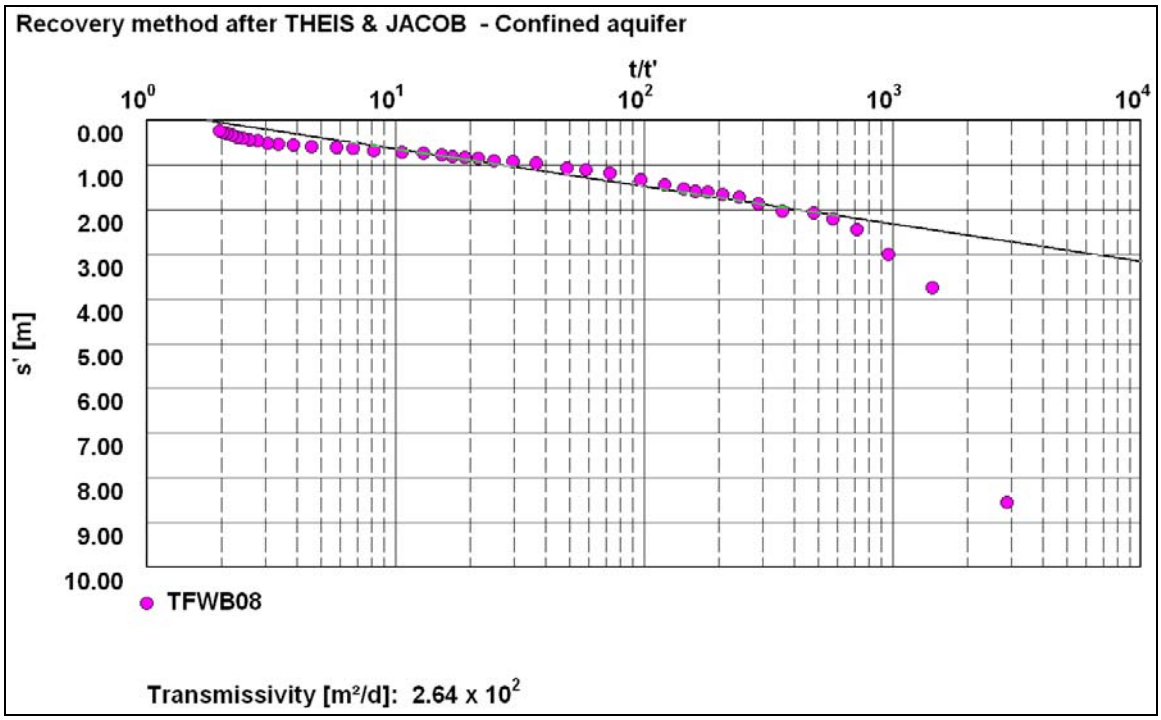

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
10^0
10^1
10^2
10^3
10^4
s' [m]
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
TFWB04
Transmissivity [m²/d]: 1.79 x 10^2

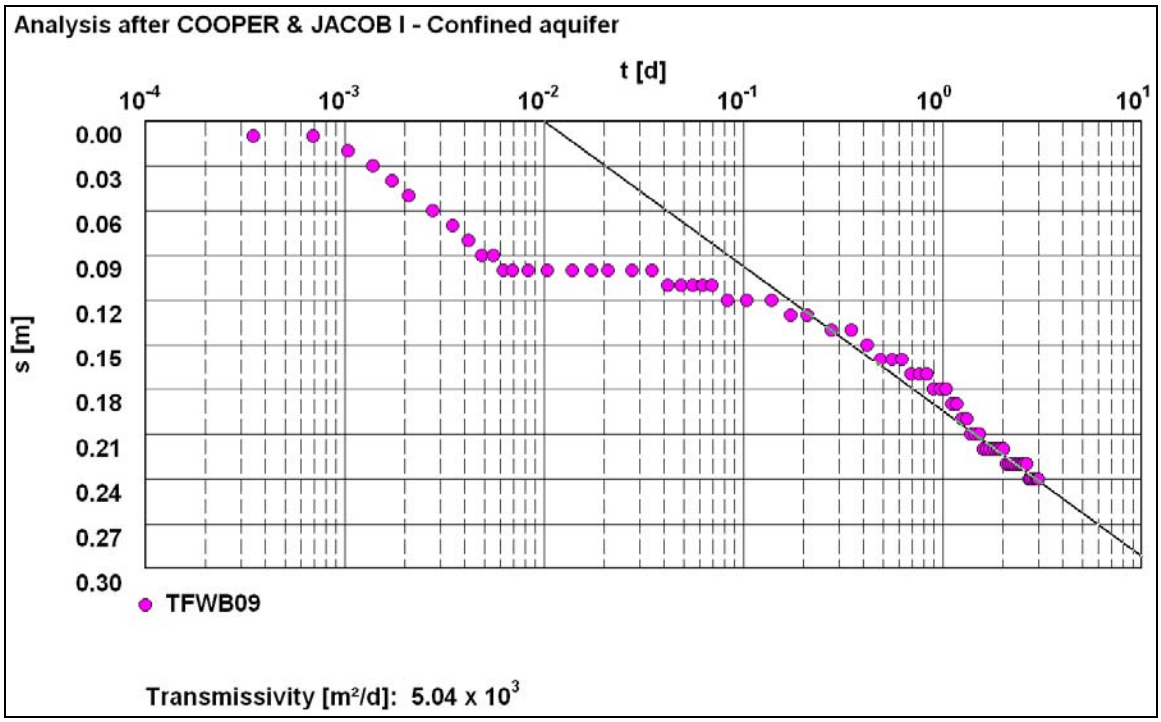

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10^-4
10^-3
10^-2
10^-1
10^0
10^1
s [m]
0.00
7.00
14.00
21.00
28.00
35.00
42.00
49.00
56.00
63.00
70.00
TFWB05
Transmissivity [m²/d]: 1.65 x 10^2

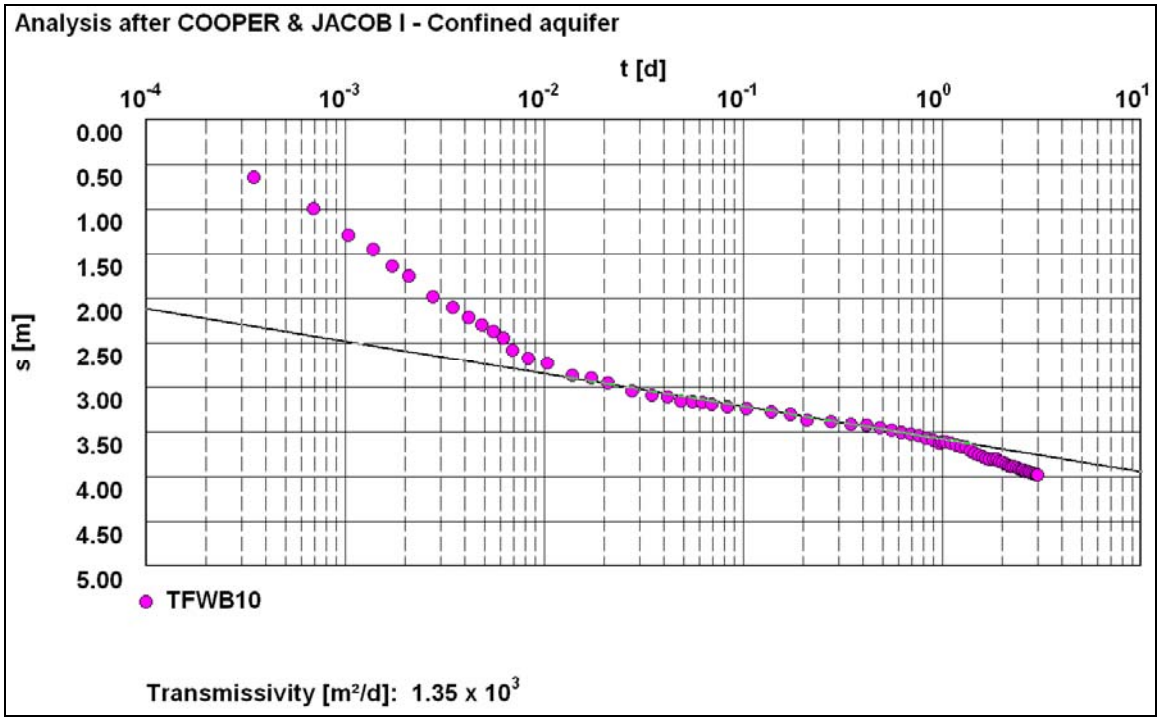

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
10^0
10^1
10^2
10^3
10^4
0.00
7.00
14.00
21.00
28.00
35.00
42.00
49.00
56.00
63.00
70.00
s' [m]
TFWB05
Transmissivity [m²/d]: 2.79 x 10^1

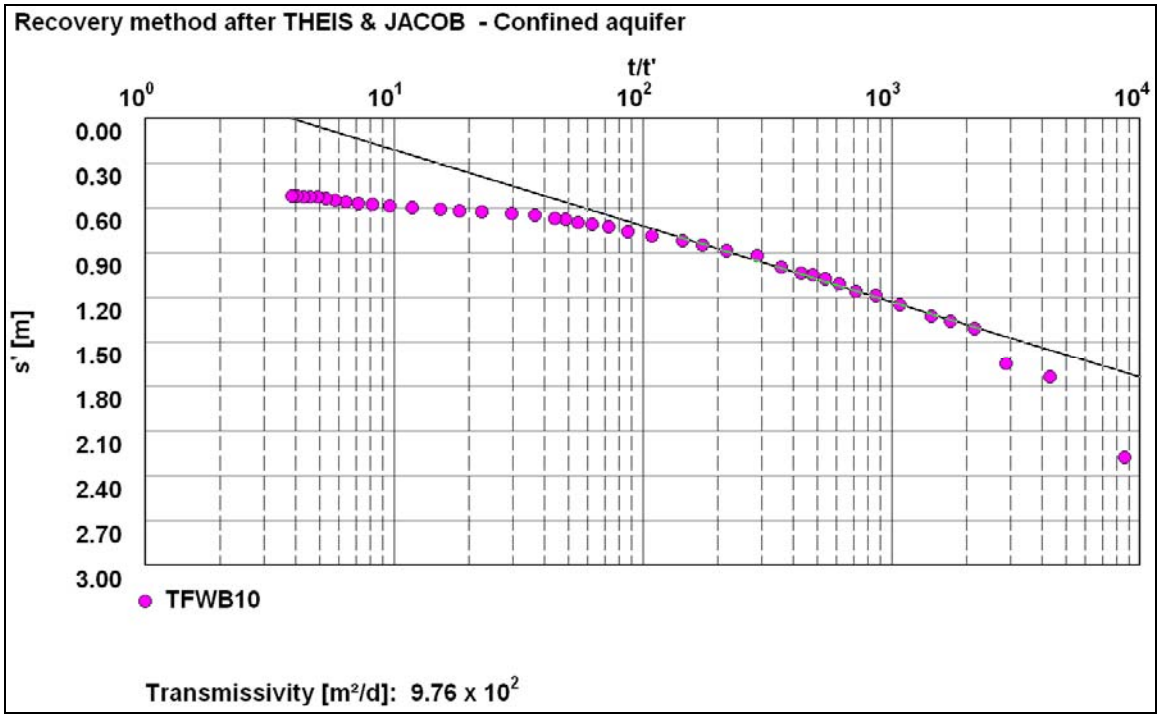

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10^-4
10^-3
10^-2
10^-1
10^0
10^1
0.00
0.70
1.40
2.10
2.80
3.50
4.20
4.90
5.60
6.30
7.00
s [m]
TFWB06A
Transmissivity [m²/d]: 4.29 x 10^3

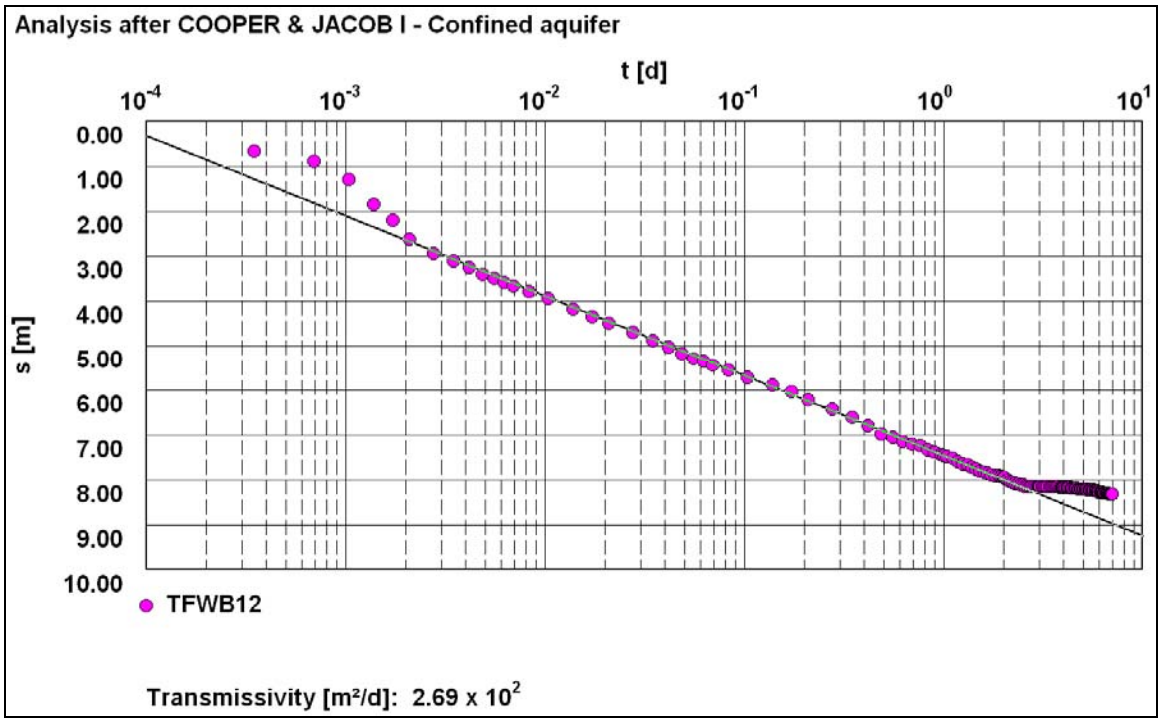

Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
s [m]
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
TFWB08
Transmissivity [m²/d]: 1.71 x 10²

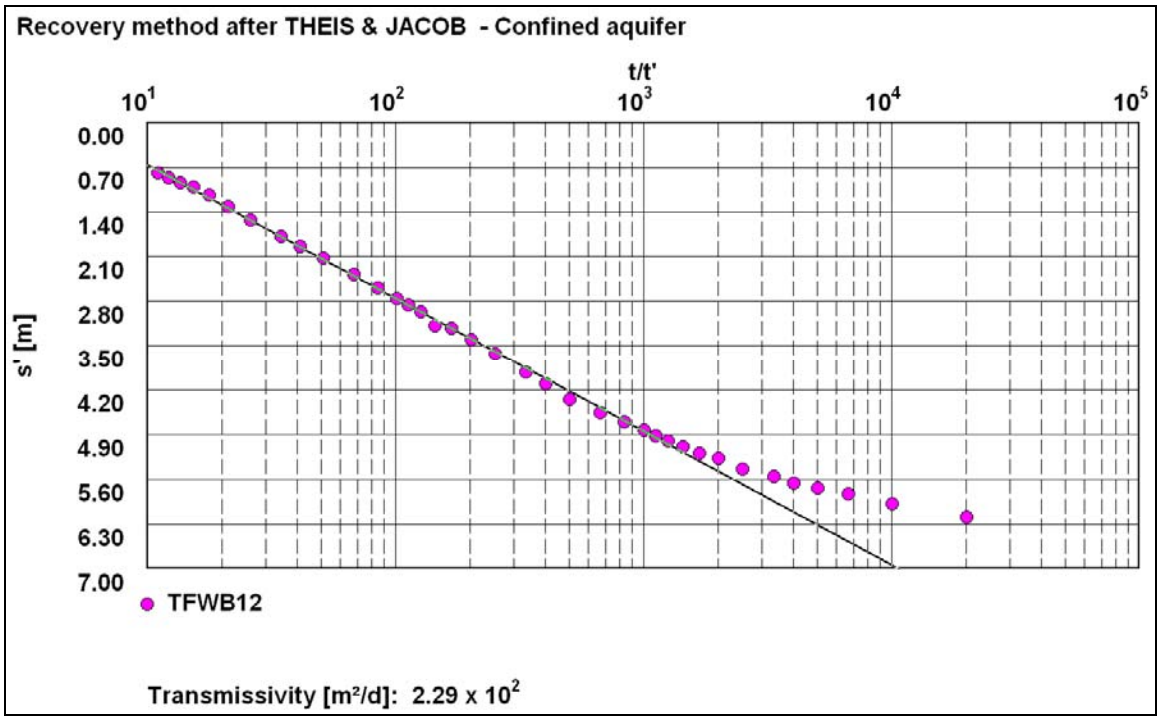

Recovery method after THEIS & JACOB - Confined aquifer
t/t'
100
101
102
103
104
s' [m]
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
TFWB08
Transmissivity [m²/d]: 2.64 x 10²


Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
101
s [m]
0.00
0.03
0.06
0.09
0.12
0.15
0.18
0.21
0.24
0.27
0.30
TFWB09
Transmissivity [m²/d]: 5.04 x 10³


Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10-4
10-3
10-2
10-1
100
101
s [m]
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
TFWB10
Transmissivity [m²/d]: 1.35 x 10³


Recovery method after THEIS & JACOB - Confined aquifer
t/t'
10^0
10^1
10^2
10^3
10^4
s' [m]
0.00
0.30
0.60
0.90
1.20
1.50
1.80
2.10
2.40
2.70
3.00
TFWB10
Transmissivity [m²/d]: 9.76 x 10^2


Analysis after COOPER & JACOB I - Confined aquifer
t [d]
10^-4
10^-3
10^-2
10^-1
10^0
10^1
s [m]
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
TFWB12
Transmissivity [m²/d]: 2.69 x 10^2


Recovery method after THEIS & JACOB - Confined aquifer
t/t'
10^1
10^2
10^3
10^4
10^5
s' [m]
0.00
0.70
1.40
2.10
2.80
3.50
4.20
4.90
5.60
6.30
7.00
TFWB12
Transmissivity [m²/d]: 2.29 x 10^2

Borehole No.	GPS Co-ordinates UTM WGS 84		Pump Test Data Analysis			Comments	
			Borehole Transmissivity Estimates (m^2/d)			Aquifer Lithology	Estimated Minimum Saturated Thickness (m)
	X	Y	Pumping (Cooper-Jacob)	Recovery (Theis)	Final Estimate		
TFWB01A	411200	8830654	1.35×10^3	1.40×10^3	1.4×10^3	Caverous and fractures dolomitic shales and dolomite	>80
TFWB02	411439	8831106	4.0×10^3	3.25×10^3	3.5×10^3	Siliceous, cavernous and brecciated dolomite	>23
TFWB03A	409430	8831551	4.81×10^3	2.00×10^3	3.50×10^3	Caverous and fractured dolomitic shales and dolomite	>60
TFWB04	409746	8832994	1.81×10^2	1.79×10^2	1.80×10^2	Fractured dolomite/limestone	8
TFWB05	406616.646	8830033.62	1.65×10^2	2.8×10^1	2.0×10^2	Fractured dolomite/limestone and fractured sandstone	75
TFWB06A	412380.428	8831243.83	4.29×10^3	Immediate Recovery	4.3×10^3	Fractured sandstone and dolomite	63
TFWB08	411439	8831106	1.7×10^2	2.64×10^2	2.0×10^2	Fractured dolomite and dolomitic shale	8
TFWB09	410181	8828539	5.0×10^3	Immediate Recovery	5.0×10^3	Caverous and fractured dolomitic shales and dolomite	>75
TFWB10	410181	8828539	$1.35x\ 10^3$	9.76×10^2	$1.2x\ 10^3$	Fractured sandstone and siltstone	75
TFWB12	410953	8827416	2.69×10^2	2.29×10^2	2.5×10^2	Fractured dolomitic shale, siltsone and sandstone	>140
CC1	423573	8835043	9.16×10^2	3.5×10^3	2.0×10^3	Fractured dolomite/limestone and sandstone	65
CC2	424276	8835658	3×10^0	1.1×10^1	1.0×10^1	Fractured dolomite/limestone and sandstone	11
TFEB01	406617	8830034	**Not Tested**				
TFEB02	406617	8830034	$1.4x\ 10^1$	4×10^0	1.0×10^1	Fractured dolomite/limestone	9
TFEB03	406617	8830034	0.15	0.2	0.15	Shist/sandstone - no fracturing	
TFEB05	406617	8830034	**Not Tested**				
TFEB06	407199	8831706	**Not Tested**				
TFEB07	406617	8830034	**Not Tested**				
TFEB08	406617	8830034	6.5×10^3	7.8×10^3	7.0×10^3	Fractured sandstone and cavernous dolomite/limstone	18
TFEB09	406617	8830034	2.5×10^1	5.7×10^0	1.5×10^1	Fractured sandstone	2
TFEB10	406617	8830034	4.95×10^3	Immediate Recovery	4.95×10^3	Caverous and fractured dolomitic siltstone and dolomite	>23
TFEB11	410953	8827416	**Not Tested**				
TFEB12	410465	8831664	**Not Tested**				

ATTACHMENT 4

GROUNDWATER QUALITY DATA

Table 1 Major Ion Analysis Report

Date Sampled	Method	Units	TFEB02	TFEB06	TFEB09	TFEB10	TFWB01A	TFWB03A	TFWB04	TFWB12A	TFWB12B	CC1	CC2
			29-Nov	27-Nov	22-Nov	27-Nov	29-Nov	27-Nov	29-Nov	28-Nov	28-Nov	22-Nov	25-Nov
sampling details	bailing	(mbgl)		27	50	50		27	37	9	50	-	-
	purging	-	1.5 hrs @ 0.8 l/s	-	-	-	18 hrs @ 20 l/s	-	-	-	-	42hrs @31 l/s	8 hrs @ 10 l/s
sample field temp.	field meters (avg)	ºC	22.5	24.0	23.7	22.7	24.7	24.8	24.5	23.7	22.4	23.0	24.2
field pH	field pH meter	pH Units	7.0	7.3	7.1	7.2	7.2	7.1	7.0	8.4	7.3	7.1	7.4
lab pH	laboratory pH meter	pH Units	8.4	8.6	8.5	8.7	8.6	8.6	8.5	8.7	8.5	8.6	8.8
field conductivity	field conductivity	mS/m	97	67	59	43	56	45	72	39	58	60	71
lab conductivity	laboratory conductivity meter	mS/m	91	61	56	43	56	46	69	42	58	59	70
total dissolved solids	gravimetric	mg/l	650	412	358	274	356	258	464	250	396	392	454
P alkalinity	titration	mg/l	<0.6	<0.6	20.0	<0.6	28.0	17.0	28.5	<0.6	<0.6	29.5	29.5
M alkalinity	titration	mg/l	574	400	339	241	296	245	400	180	250	323	392
total hardness as $CaCO_3$			611	413	362	250	339	262	433	231	350	366	420
Bacteriological													
total Coli.	colliert quanti-tray method	per 100ml	NA	190	11	0	NA	1986	35	NA	NA	71	72
E. Coli.	Colliert quanti-tray method	per 100ml	NA	0	0	0	NA	0	0	NA	NA	0	0
cations													
calcium	ICP-OES	mg/l	69	47	61	36	59	21	62	17	54	55	36
magnesium	ICP-OES	mg/l	107	72	51	39	47	51	68	46	52	56	80
potassium	ICP-OES	mg/l	2.0	0.6	1.7	1.1	2.1	4.0	2.8	2.4	2.7	2.3	1.7
sodium	ICP-OES	mg/l	7.7	2.9	1.4	1.7	1.9	1.9	9.7	2.9	3.5	3.8	8.5
manganese	ICP-OES	mg/l	0.05	<0.05	<0.05	0.11	0.26	0.81	<0.05	0.07	<0.05	<0.05	<0.05
iron	ICP-OES	mg/l	<0.05	0.16	<0.05	0.10	<0.05	0.06	0.13	0.05	0.15	<0.05	<0.05
Anions													
fluoride	supressed IC	mg/l	0.4	0.3	0.2	0.4	0.1	0.8	0.3	0.2	0.2	0.5	<0.1
chloride	supressed IC	mg/l	0.8	0.5	0.4	0.8	0.7	2.1	15.7	0.9	1.1	0.4	0.4
nitrate as nitrogen	supressed IC	mg/l	0.8	0.3	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0
nitrate NO_3		mg/l	3.4	1.3	0.8	<0.3	0.5	<0.3	<0.3	<0.3	<0.3	1.3	<0.3
sulphate	supressed IC	mg/l	4.3	5.3	6.2	3.9	23.3	2.6	9.5	51.2	91.8	21.4	14.4
phosphate	supressed IC	mg/l	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8	<0.8
silica	ICP-OES	mg/l	18.7	11.7	8.6	6.7	7.9	6.9	11.4	0.5	9.3	13.1	19.5
Total Cations			**12.63**	**8.44**	**7.35**	**5.11**	**6.95**	**5.47**	**9.19**	**4.81**	**7.24**	**7.55**	**8.85**
Total Anions			**11.08**	**7.66**	**7.11**	**4.61**	**6.94**	**5.29**	**9.09**	**4.14**	**6.79**	**7.80**	**9.21**
Difference			**1.55**	**0.78**	**0.24**	**0.50**	**0.01**	**0.18**	**0.11**	**0.68**	**0.45**	**-0.25**	**-0.36**
% Difference			**6.55**	**4.83**	**1.67**	**5.18**	**0.04**	**1.67**	**0.58**	**7.56**	**3.23**	**-1.62**	**-2.00**

Table 2 Groundwater Sample Report - ICP MS

Sample No:	Ag	Al	As	Au	B	Ba	Be	Bi	Ca	Cd	Ce	Co
TFEB02	<0.001	<0.001	<0.001	<0.001	0.013	0.407	<0.001	<0.001	68.6	<0.001	<0.001	0.001
TFEB06	<0.001	0.008	<0.001	<0.001	0.016	0.127	<0.001	<0.001	46.5	<0.001	<0.001	0.001
TFEB09	<0.001	0.003	<0.001	<0.001	0.001	0.583	<0.001	<0.001	47.0	<0.001	<0.001	<0.001
TFEB10	<0.001	0.005	<0.001	<0.001	0.003	0.036	<0.001	<0.001	60.6	<0.001	<0.001	0.001
TFWB01A	<0.001	<0.001	<0.001	<0.001	0.004	0.249	<0.001	<0.001	58.9	<0.001	<0.001	0.06
TFWB03A	<0.001	<0.001	<0.001	<0.001	0.005	0.275	<0.001	<0.001	21.2	<0.001	<0.001	0.002
TFWB04	<0.001	0.001	<0.001	<0.001	0.007	0.543	<0.001	<0.001	62.1	<0.001	<0.001	0.001
TFWB12A	<0.001	<0.001	<0.001	<0.001	0.008	0.076	<0.001	<0.001	16.6	<0.001	<0.001	<0.001
TFWB12B	<0.001	<0.001	<0.001	<0.001	0.009	0.093	<0.001	<0.001	54.0	<0.001	<0.001	<0.001
CC1	<0.001	0.005	<0.001	<0.001	0.006	0.135	<0.001	<0.001	54.5	<0.001	<0.001	<0.001
CC2	<0.001	<0.001	0.020	<0.001	0.014	0.789	<0.001	<0.001	36.1	<0.001	<0.001	0.007

Sample No:	Cr	Cs	Cu	Fe	Ga	Ge	Hg	Ho	In	Ir	K	La	Li
TFEB02	<0.001	<0.001	0.001	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1.960	<0.001	0.050
TFEB06	<0.001	<0.001	<0.001	0.162	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.604	<0.001	0.023
TFEB09	<0.001	<0.001	0.001	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1.680	<0.001	0.008
TFEB10	<0.001	<0.001	0.001	<0.095	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1.070	<0.001	0.014
TFWB01A	<0.001	<0.001	0.076	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	2.120	<0.001	0.017
TFWB03A	<0.001	<0.001	0.001	0.060	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	4.000	<0.001	0.031
TFWB04	<0.001	<0.001	0.001	0.130	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	2.780	<0.001	0.028
TFWB12A	<0.001	<0.001	<0.001	0.054	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	2.440	<0.001	0.013
TFWB12B	<0.001	<0.001	0.002	0.148	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	2.700	<0.001	0.012
CC1	<0.001	<0.001	0.001	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	2.330	<0.001	0.018
CC2	<0.001	<0.001	<0.001	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	1.680	<0.001	0.022

All metals presented as mg/L

Table 2 Groundwater Sample Report - ICP MS (continued)

Sample No:	Mg	Mn	Mo	Na	Nb	Nd	Ni	Pb	Pt	Rb	Sb	Sc
TFEB02	107.0	0.054	0.001	7.650	<0.001	<0.001	0.006	<0.001	<0.001	0.005	<0.001	1.275
TFEB06	72.3	0.019	0.001	2.920	<0.001	<0.001	0.009	<0.001	<0.001	0.001	<0.001	1.280
TFEB09	51.1	0.003	0.002	1.370	<0.001	<0.001	0.004	<0.001	<0.001	0.002	<0.001	1.248
TFEB10	38.7	0.114	0.001	1.670	<0.001	<0.001	0.010	<0.001	<0.001	0.001	<0.001	1.253
TFWB01A	46.6	0.255	0.001	1.920	<0.001	<0.001	0.007	<0.001	<0.001	0.004	<0.001	1.211
TFWB03A	50.9	0.807	0.001	1.900	<0.001	<0.001	0.015	<0.001	<0.001	0.010	<0.001	1.225
TFWB04	67.7	0.043	0.002	9.740	<0.001	<0.001	0.023	<0.001	<0.001	0.006	<0.001	1.245
TFWB12A	46.0	0.068	0.002	2.940	<0.001	<0.001	0.002	<0.001	<0.001	0.004	<0.001	1.228
TFWB12B	52.3	0.015	0.001	3.540	<0.001	<0.001	0.005	<0.001	<0.001	0.004	<0.001	1.207
CC1	55.8	0.01	<0.001	3.770	<0.001	<0.001	0.004	<0.001	<0.001	0.004	<0.001	1.174
CC2	80.3	0.019	0.003	8.470	<0.001	<0.001	0.006	<0.001	<0.001	0.007	<0.001	1.189

Sample No:	Se	Sn	Sr	Ta	Te	Th	Yl	U	V	W	Y	Zn	Zr
TFEB02	0.001	<0.001	0.222	<0.001	<0.001	<0.001	<0.001	0.002	0.001	<0.001	<0.001	0.056	<0.001
TFEB06	0.002	<0.001	0.863	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.016	<0.001
TFEB09	0.002	<0.001	0.151	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	0.022	<0.001
TFEB10	0.002	<0.001	0.099	<0.001	<0.001	<0.001	<0.001	0.000	<0.001	<0.001	<0.001	0.012	<0.001
TFWB01A	0.001	<0.001	0.876	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.024	<0.001
TFWB03A	0.001	<0.001	0.066	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.020	<0.001
TFWB04	0.002	<0.001	0.584	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.024	<0.001
TFWB12A	0.001	<0.001	0.078	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005	<0.001
TFWB12B	0.001	<0.001	0.548	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.014	<0.001
CC1	0.001	<0.001	0.327	<0.001	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001	0.018	<0.001
CC2	0.001	<0.001	0.584	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.029	<0.001

All metals presented as mg/L

APPENDIX C2.12-I

TENKE FUNGURUME

ANALYSIS OF TRANSPORT OF CONSTITUENTS IN GROUNDWATER

An analytical groundwater transport model was developed to assess the migration of constituents associated with seepage from:

- Waste-rock pile.
- Two long-term ore stockpiles.
- Tailings facility.
- High-grade run-of-mine (ROM) ore storage areas.
- Post-closure pit lake.

The analytical groundwater transport model (hereafter termed attenuation model) was developed based on the results of the groundwater flow model (Section C2.10). The groundwater flow model was developed to represent groundwater flow during mining and closure. The groundwater flow model provided inputs to the attenuation model in terms of the time of travel for groundwater from the various facilities to surface water discharge locations. As a result of the sensitivity of the model results to the interpreted geological conditions at the site, two groundwater flow scenarios based on differing groundwater flow assumptions were evaluated as described in the hydrogeology impact assessment (Section C2.10). The two groundwater flow scenarios are thought to provide an indication of the range of responses to be expected within the groundwater flow regime at Kwatebala. For each of the seepage sources, the higher of the flows to each watercourse from each of the two scenarios was used in the groundwater transport modeling. Using the highest flow represents the most conservative assumption over the ranges of responses expected within the groundwater flow regime.

Methods

The evaluation was performed using a one-dimensional, analytical model of groundwater flow and chemical transport (Ogata and Banks 1961). The Ogata and Banks (1961) model was extended to consider retardation of chemical transport due to reactions with the aquifer matrix using equations presented in Domenico and Schwartz (1990).

The solution for one-dimensional transport presented by Ogata and Banks (1961) is:

$$C(x,t) = \frac{C_0}{2} erfc\left[\frac{(x - vt)}{2(\alpha_x vt)^{1/2}}\right]$$

with

x = distance along flow path
t = time
C(x,t) = concentration at time t and distance x along the flowpath
C0 = initial or source concentration
v = groundwater pore velocity
αx = longitudinal dispersivity
erfc = complimentary error function

Domenico and Schwartz (1990) extend the Ogata and Banks (1961) solution to include retardation, resulting in the following equation:

$$C(x,t) = \frac{C_0}{2} erfc\left[\frac{(R_f x - vt)}{2(\alpha_x v R_f t)^{1/2}}\right]$$

with R_f = retardation factor, and other terms in the equation as described above.

The retardation factor describes the relative velocity of water to the contaminant front in the saturated zone. A retardation factor of 1 implies that the contaminant front is moving at the same velocity as groundwater, while retardation factors greater than 1 indicate that the contaminant front is moving along the flowpath at a velocity slower than the groundwater.

Retardation factors were calculated for each constituent using the following equation:

$$R_f = 1 + K_d\left(\frac{\rho_b}{n_e}\right)$$

with

K_d = distribution coefficient
ρ_b = bulk density of rock or sediment
n_e = effective porosity

The distribution coefficient K_d is a chemical parameter that represents the partitioning of a constituent between liquids and solids along the flowpath under the assumption that the chemical reactions responsible for the partitioning are fast, reversible and can be described by a linear sorption isotherm.

Calculation of Mass Flux to Surface Water

Volumetric seepage estimates from the waste rock and ore stockpiles and constituent concentrations for metals, major cations and major anions were obtained from the surface water hydrology impact assessment (Section C2.11). The volumetric seepage rate was multiplied by the low-range and high-range concentration estimate to arrive at a range of mass flux for each constituent from each source reaching groundwater. Loading factors were calculated as the fraction of mass flux from the seepage source entering each surface water body.

The model was used to evaluate the likely time of first arrival for constituents from each of the three sources, and also to evaluate the likely time of arrival of constituents from the furthest portion of the source away from the receiving stream by evaluating the argument β to the complimentary error function, erfc(β).

As described by Domenico and Schwartz (1990), concentrations are effectively zero at distances and times where β is greater than two. For β=2, erfc(β) is on the order of 1×10^{-3} and calculated concentrations are very close to zero. This represents conditions ahead of the constituent front in the groundwater flow system. Conversely, for distances and times where β is less than -2, concentrations are nearly equal to the source concentration C_0. For β=-2, erfc(β) is about 1.999, and calculated concentrations are therefore very close to C_0.

These bounding values (+2, -2) for β were evaluated in the retardation equation described by Domenico and Schwartz (1990) to calculate the time of first arrival and the time of arrival for constituents from the furthest points from the receiving surface water. The time of initial arrival was used to determine when mass flux to the receiving surface water would start to increase from zero, and the time of arrival of the furthest constituents was used to determine when the mass flux would be equal to the full solute mass in seepage from the source area.

Nitrate plus Nitrite

Nitrate plus nitrite was treated as a special case. It is expected that the majority of nitrate plus nitrite which enters the groundwater will be from blasting residue. Therefore, the inputs of nitrate plus nitrite which enter the groundwater should be minimal once mining operations cease. It was assumed in the attenuation model that the input of nitrate plus nitrite would only occur for 20 years after closure After this point it is assumed that the blasting residue would be largely dissolved and there will be no significant inputs of nitrate plus nitrite. Loading for nitrate plus nitrite were adjusted to reflect this by calculating the loading for any give date using the standard technique, and subtracting the loading occurring 20 years after this date.

Assumptions

Major assumptions inherent in this analytical method include:

- Groundwater flow is effectively one-dimensional between the source and the point of entry to the stream.
- The groundwater regime can be represented as an equivalent porous medium over the flow path lengths.
- Groundwater flow is steady and uniform along the flowpath.
- Reactions along the flowpath are reversible and can be adequately represented by a linear adsorption isotherm.
- Mass flux into the receiving surface water increases linearly between the time of initial arrival and the time of arrival for constituents from the furthest point from the receiving body.
- Mass flux into the receiving surface water changes at the time of closure due to reduction in the volumetric flow of seepage from the waste-rock pile and ore stockpiles after operations cease.

Input Data and Parameter Values

Input data and parameter values used in this evaluation are summarized in Tables 1 through 6. Water quality inputs from each source used in the model are provided in the geochemistry technical report (Appendix B2.3-I) and are summarized in Table 7. The water quality inputs for waste rock and LT ore assume the presence of geochemical controls that reduce concentrations for certain parameters relative to conservative behavior. These controls include precipitation of mineral phases that limit dissolved concentrations of certain constituents.

Table 1 Seepage Rates from Source Areas

Source	Flow (m^3/d), Scenarios 1 & 2		Flow (m^3/d) Out of Pit, Long-term Post-closure	
	Operations	Closure	Scenario 1	Scenario 2
Kasana waste rock facility	1,037	695	N/A	N/A
ore stockpile east	627	384	N/A	N/A
ore stockpile southwest	313	192	N/A	N/A
tailings facility	5.5E-04	5.5E-04	N/A	N/A
ROM ore stockpiles	47	0	N/A	N/A
pit lake to Dipeta, long-term	N/A	N/A	10,500	1,850
pit lake to Mofia, long-term	N/A	N/A	0	1,850

Notes: Seepage from tailings facility captured by pit-dewatering system during operations.
ROM ore stockpiles assumed to be removed at closure.

Source: hydrogeology impact assessment (Section C2.10).

N/A = not applicable

Table 2 Groundwater Flow Velocities

Source	Average Groundwater Velocity along Flow Path (m/d)	
	Scenario 1	Scenario 2
Kasana waste rock facility	0.03	0.06
ore stockpile east	0.01	0.07
ore stockpile southwest	N/A	0.05
tailings facility	0.03	0.06
ROM ore stockpiles	N/A	0.05
Pit lake to Dipeta, long-term	0.10	0.07
Pit lake to Mofia, long-term	N/A	0.04

Notes: Flow from southwest ore stockpile within capture zone of pit dewatering under Scenario 1.

Proposed area for ROM ore stockpiles assumed to be near southwest ore stockpile, therefore groundwater velocities from southwest ore stockpile used for ROM ore seepage analysis.

Table 3 Transport Parameters

Parameter	Value	Units
porosity	0.05	dimensionless
bulk density	2.385	g/cm^3

Table 4 Flow Path Distances to Receiving Surface Water

Source	Estimated Flow Path Length to Surface Water		
	Min (m)	Max (m)	Average (m)
Kasana waste rock facility	20	320	170
ore stockpile east	20	350	185
ore stockpile southwest	75	435	255
tailings facility	20	320	170
ROM ore stockpiles	400	450	425
pit to Dipeta, long-term	250	600	425
pit to Mofia, long-term	500	750	625

Table 5 Dispersivity Values

Source	Dispersivity (m)
Kasana waste rock facility	17
ore stockpile east	18.5
ore stockpile southwest	25.5
tailings facility	17
ROM ore stockpiles	42.5
pit lake to Dipeta, long-term	42.5
pit lake to Mofia, long-term	62.5

Note: Assumed values, 10% of average flowpath length.

Table 6 Distribution Coefficients and Retardation Factors

Constituent	K_d (ml/g)	R_f
silver	4	192
antimony	6	287
cobalt	8.81	421
tin	10	478
selenium	14.9	712
iron	15	717
arsenic	19.4	926
manganese	25.3	1,208
phosphorus	50	2,386
uranium	50	2,386
chromium	56.5	2,696
nickel	58.6	2,796
copper	92.2	4,399
strontium	100	4,771
vanadium	100	4,771
molybdenum	120	5,725
cadmium	423	20,178
mercury	580	27,667
lead	597	28,478
zinc	939	44,791
beryllium	1,400	66,781
barium	2,800	133,561
aluminum	35,300	1,683,811
calcium	0	1
chloride	0	1
nitrate	0	1
sulfate	0	1
magnesium	1,400	66,781
potassium	0.2	11
sodium	0.2	11

Note: K_d values from Stenge and Peterson, 1989.

Table 7 Seepage Concentrations at Source Areas

Constituent	Total Metals							
	Waste Rock[a]		LT Ore[a]		Tailings		Pit Post-Closure	
	Max (mg/L)	Min (mg/L)	Max (mg/L)	Min (mg/L)	Max (mg/L)	Min (mg/L)	Max (mg/L)	Min (mg/L)
silver	0.013	0.0013	0.0032	0.001	0.001	0.001	0.01	0.003
antimony	0.013	0.0013	0.013	0.0013	0.063	0.0035	0.02	0.01
cobalt	0.75	0.0029	1.4	0.40	0.46	0.011	0.06	0.03
tin	0.013	0.0013	0.013	0.0013	0.0017	0.0010	0.0100	0.0100
selenium	0.133	0.0133	0.013	0.0013	0.20	0.0092	0.1	0.006
iron	0.001	0.001	0.001	0.001	0.058	0.001	0.001	0.01
arsenic	0.013	0.0013	0.032	0.0011	0.16	0.0043	0.01	0.003
manganese	0.97	0.0041	0.21	0.014	0.063	0.002	0.1	0.04
phosphorus	1.3	0.13	1.9	0.14	4	0.04	1.3	0.3
uranium	0.014	0.0013	0.0064	0.0039	0.0029	0.001	0.01	0.01
chromium[b]	0.015	0.0013	0.032	0.0032	0.045	0.0028	0.02	0.004
nickel	0.12	0.0038	0.071	0.0018	0.013	0.001	0.04	0.01
copper	0.020	0.015	0.054	0.020	0.13	0.01	0.02	0.10
strontium	2.0	0.025	0.12	0.0033	13	0.59	0.2	0.2
vanadium	0.013	0.0013	0.013	0.0013	0.015	0.001	0.01	0.01
molybdenum	0.31	0.0028	0.045	0.0016	2.1	0.045	0.03	0.03
cadmium	0.013	0.0013	0.0026	0.0016	0.001	0.001	0.005	0.002
mercury	0.013	0.0013	0.0013	0.0013	0.001	0.001	0.01	0.001
lead	0.083	0.0024	0.013	0.0013	0.0012	0.001	0.02	0.003
zinc	0.57	0.018	0.45	0.017	0.012	0.001	0.6	0.02
beryllium	0.013	0.0013	0.013	0.0013	0.0012	0.001	0.01	0.001
barium	0.051	0.0085	0.034	0.0034	0.22	0.0046	0.05	0.05
aluminum	2.1	0.017	0.84	0.029	0.012	0.0013	0.2	0.1
calcium	18	0.15	9.3	0.63	4008	338	14	14
chloride	418	7	122	0.86	699	6.1	66	4.3
nitrate	13	13	9	9	0	0	13	13
sulfate	964	7	193	4	14696	899	68	13
magnesium	209	4	17	1	1179	4	13	9
potassium	269	26	208	9	1237	4	262	4
sodium	192	0.2	43	0.4	636	6	2	1

[a] Presence of geochemical controls assumed

Summary of Results

Results of the attenuation model are summarized in Table 8. Table 8 shows the estimated mass flux for each constituent 1,000 years after the start of operations. Results are expressed as loading to either the Kasana/Mofia or Dipeta surface-water river network in terms of kilograms per year for each constituent. Mass-flux estimates are shown as bounding calculations, with a maximum potential flux based on high groundwater-velocity estimates and high seepage

concentrations and minimum potential flux based on low groundwater-velocity estimates and minimum seepage concentrations.

Due to the differences in retardation factors and concentrations in seepage from the waste-rock and ore stockpiles, each constituent can be expected to reach the nearby surface water at a unique time and mass flux. The fronts of constituents with retardation factors equal to 1 move at the velocity of groundwater and will be the first to arrive at the receiving surface water. The fronts of constituents with retardation factors greater than 1 will move at an apparent velocity slower than the groundwater, with the ratio of groundwater velocity to apparent constituent velocity equal to the retardation factor. Thus, constituents with relatively low retardation factors that are greater than 1 will arrive at the receiving surface waters before constituents with greater retardation factors.

Detailed results for each of the constituents are provided in Data Sheets 1 to 30. Results are expressed as loading to either the Kasana/Mofia or Dipeta surface-water river network in terms of kilograms per year for each constituent reporting to the stream network from each potential source. Loading factors presented in the detailed data sheets are the proportion of mass loading from each seepage source entering the receiving surface water. Mass-flux calculations were carried out in the attenuation model to a maximum time of 10,000 years from the start of operations at Tenke Fungurume.

Table 8 Summary of Mass-Loading Estimates 1,000 Years After Start of Mining

Parameter	Maximum Total Loading Kasana/Mofia (Kg/yr)	Minimum Total Loading Kasana/Mofia (Kg/yr)	Loadings to Kasana/Mofia by Source (Kg/yr)												Loadings to Dipeta Kg/year	
			Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)
Nutrients																
nitrate + nitrite	4800	2500	2300	1070	970	180	260	0	0	0	20	0	1250	1250	17000	2600
total phosphate	7	0.16	4	0.14	3	0.018	0	0	<0.00001	<0.00001	0	0	0	0	0	0
Major ions																
calcium	16000	9600	4600	40	1300	90	650	0	0.80	0.068	0	0	9500	9500	53700	9500
chloride	177000	4700	106000	1700	17000	120	8600	0	0.14	0.0012	0	0	45000	2900	250000	2900
magnesium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
potassium	208000	8700	68000	6600	29000	640	15000	0	0.25	0.00090	0	0	96000	1400	1000000	2600
sodium	59000	600	49000	42	6000	28	3000	0	0.13	0.0013	0	0	620	500	6500	950
sulfate	330000	11000	240000	1700	27000	550	14000	0	3	0.18	0	0	46000	8800	260000	8800
Total Metals																
aluminum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
antimony	0.57	0.018	0.34	0.02	0.18	0.003	0.044	0	<0.00001	<0.00001	0	0	0	0	3.0	0.08
arsenic	0.26	0.0050	0.10	0.004	0.14	0.001	0.02	0	<0.00001	<0.00001	0	0	0	0	0	0
barium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
beryllium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cadmium	0.00002	0	0	0	0.00002	0	0	0	0	0	0	0	0	0	0	0
chromium	0.078	0.0014	0.035	0.0011	0.043	0.0003	0	0	<0.00001	<0.00001	0	0	0	0	0	0
cobalt	29	0.68	13	0.023	13	0.66	2.9	0	0.00001	<0.00001	0	0	0	0	3.5	0
copper	0.065	0.0054	0.025	0.0054	0.040	0	0	0	<0.00001	<0.00001	0	0	0	0	0	0
iron	0.016	0.0053	0.010	0.0044	0.0056	0.00088	0.00096	0	<0.00001	<0.00001	0	0	0	0	0	0
lead	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
manganese	6.3	0.016	5.6	0.010	0.67	0.0060	0.063	0	<0.00001	<0.00001	0	0	0	0	0	0
mercury	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
molybdenum	0.29	0.00052	0.27	0.00052	0.024	0	0	0	<0.00001	<0.00001	0	0	0	0	0	0
nickel	0.35	0.0033	0.26	0.0032	0.090	0.00014	0	0	<0.00001	<0.00001	0	0	0	0	0	0
selenium	1.4	0.060	1.3	0.059	0.072	0.0011	0.013	0	0.000002	<0.00001	0	0	0	0	0	0
silver	0.60	0.027	0.51	0.023	0.068	0.0038	0.017	0	0.00000003	<0.00001	0	0	0	0	2.9	0.072
strontium	2.3	0.0077	2.2	0.0077	0.077	0	0	0	0.00001	<0.00001	0	0	0	0	0	0
tin	0.34	0.011	0.20	0.0089	0.11	0.0019	0.023	0	<0.00001	<0.00001	0	0	0	0	0.36	0
uranium	0.047	0.0019	0.038	0.0014	0.010	0.00049	0	0	<0.00001	<0.00001	0	0	0	0	0	0
vanadium	0.024	0.00040	0.015	0.00040	0.0086	0	0	0	<0.00001	<0.00001	0	0	0	0	0	0
zinc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

References

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Stenge, D.L. and S.R. Peterson. 1989. Chemical Data Bases for the Multimedia Environmental Pollutant Assessment System (MEPAS): Version 1. Battelle Memorial Institute, December 1989.

DATA SHEET 1 - barium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	133561		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	16,108	7,517
	1	9,770,762	4,559,689
Ore Stockpile East	0	34,170	6,378
	1	24,375,324	4,550,060
Ore Stockpile Southwest	0	N/A	75,624
	1	N/A	8,152,336
Tailings Facility	0	16,108	7,517
	1	9,770,762	4,559,689
ROM Ore Stockpiles	0	N/A	864,697
	1	N/A	10,598,827
Pit to Dipeta	0	197,885	309,168
	1	5,921,124	9,251,728
Pit to Mofia	0	N/A	1,192,152
	1	N/A	20,020,487

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	2425.61818	5883623.55	16108.48337
	b	1030.37	1508.30	Scenario 2	1657.01267	2745690.99	7517.292238
	c	-2671220	-2671220				
Full Contribution	a	0.03	0.06	Scenario 1	59739.19	3,568,770,946	9,770,762
	b	-1030.37	-1508.30	Scenario 2	40809.64	1,665,426,441	4,559,689
	c	-42739520	-42739520				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	3532.78105	12,480,542	34,170
	b	710.96	1645.54	Scenario 2	1526.33586	2,329,701	6,378
	c	-2671220	-2671220				
Full Contribution	a	0.01	0.07	Scenario 1	94356.17	8,903,087,096	24,375,324
	b	-710.96	-1645.54	Scenario 2	40766.53	1,661,909,591	4,550,060
	c	-46746350	-46746350				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	1644.99	Scenario 2	5255.63404	27,621,689	75,624
	c	-10017075	-10017075				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-1644.99	Scenario 2	54567.7634	2,977,640,802	8,152,336
	c	-58099035	-58099035				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	2425.618	5,883,624	16,108
	b	1030.37	1508.30	Scenario 2	1657.013	2,745,691	7,517
	c	-2671220	-2671220				
Full Contribution	a	0.03	0.06	Scenario 1	59739.19	3,568,770,946	9,770,762
	b	-1030.37	-1508.30	Scenario 2	40809.64	1,665,426,441	4,559,689
	c	-42739520	-42739520				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	2123.67	Scenario 2	17771.62	315,830,438	864,697
	c	-53424400	-53424400				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-2123.67	Scenario 2	62219.14	3,871,221,725	10,598,827
	c	-60102450	-60102450				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	8500.554	72,259,412	197,885
	b	3054.66	2443.73	Scenario 2	10625.69	112,905,332	309,168
	c	-33390250	-33390250				
Full Contribution	a	0.10	0.07	Scenario 1	46504.54	2,162,672,306	5,921,124
	b	-3054.66	-2443.73	Scenario 2	58130.68	3,379,175,477	9,251,728
	c	-80136600	-80136600				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	2342.82	Scenario 2	20866.61	435,415,339	1,192,152
	c	-66780500	-66780500				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-3054.66	-2342.82	Scenario 2	85512.95	7,312,464,750	20,020,487
	c	-100170750	-100170750				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

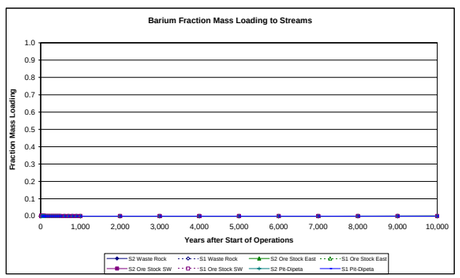
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-04	3.57E-04	0.00E+00	1.06E-04	0.00E+00	0.00E+00	0.00E+00
9,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.26E-04	5.77E-04	0.00E+00	3.26E-04	0.00E+00	0.00E+00	0.00E+00
10,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.45E-04	7.97E-04	0.00E+00	5.45E-04	0.00E+00	0.00E+00	0.00E+00

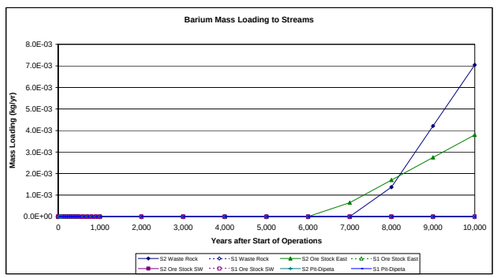
Loading Calculations to Kasana (kg/year)

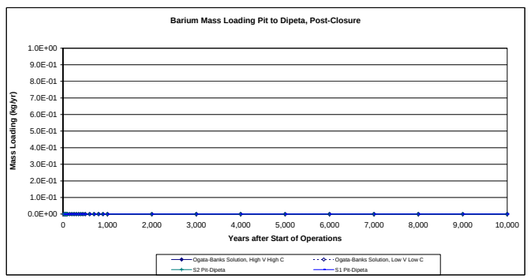
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	1.37E-03	0.00E+00	6.52E-04	0.00E+00	1.70E-03	0.00E+00	4.58E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9,000	4.21E-03	0.00E+00	2.75E-03	0.00E+00	3.80E-03	0.00E+00	1.41E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10,000	7.05E-03	0.00E+00	3.80E-03	0.00E+00	0.00E+00	0.00E+00	2.35E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Ogata-Banks Solution, High V High C: Post-closure Loading to Dipeta, Scenario 1 (kg/yr)				Ogata-Banks Solution, Low V Low C: Post-closure Loading to Dipeta, Scenario 2 (kg/yr)			
Beta	erfc (Beta)	Mass Loading (kg/yr)		Beta	erfc (Beta)	Mass Loading (kg/yr)	
N/A	N/A	0	N/A		N/A	0	N/A
N/A	N/A	0	N/A		N/A	0	N/A
N/A	N/A	0	N/A		N/A	0	N/A
N/A	N/A	0	N/A		N/A	0	N/A
6.15E+02	0.0	0.00E+00		7.69E+02	0.0	0.00E+00	
4.35E+02	0.0	0.00E+00		5.44E+02	0.0	0.00E+00	
3.55E+02	0.0	0.00E+00		4.44E+02	0.0	0.00E+00	
3.08E+02	0.0	0.00E+00		3.84E+02	0.0	0.00E+00	
2.75E+02	0.0	0.00E+00		3.44E+02	0.0	0.00E+00	
1.95E+02	0.0	0.00E+00		2.43E+02	0.0	0.00E+00	
1.59E+02	0.0	0.00E+00		1.99E+02	0.0	0.00E+00	
1.38E+02	0.0	0.00E+00		1.72E+02	0.0	0.00E+00	
1.23E+02	0.0	0.00E+00		1.54E+02	0.0	0.00E+00	
1.12E+02	0.0	0.00E+00		1.40E+02	0.0	0.00E+00	
1.04E+02	0.0	0.00E+00		1.30E+02	0.0	0.00E+00	
9.72E+01	0.0	0.00E+00		1.22E+02	0.0	0.00E+00	
9.17E+01	0.0	0.00E+00		1.15E+02	0.0	0.00E+00	
8.29E+01	0.0	0.00E+00		1.04E+02	0.0	0.00E+00	
7.63E+01	0.0	0.00E+00		9.54E+01	0.0	0.00E+00	
7.10E+01	0.0	0.00E+00		8.88E+01	0.0	0.00E+00	
6.67E+01	0.0	0.00E+00		8.34E+01	0.0	0.00E+00	
6.31E+01	0.0	0.00E+00		7.89E+01	0.0	0.00E+00	
4.40E+01	0.0	0.00E+00		5.50E+01	0.0	0.00E+00	
3.57E+01	0.0	0.00E+00		4.47E+01	0.0	0.00E+00	
3.09E+01	0.0	0.00E+00		3.86E+01	0.0	0.00E+00	
2.76E+01	0.0	0.00E+00		3.45E+01	0.0	0.00E+00	
2.51E+01	0.0	0.00E+00		3.14E+01	0.0	0.00E+00	
2.32E+01	0.0	0.00E+00		2.91E+01	0.0	0.00E+00	
2.17E+01	0.0	0.00E+00		2.72E+01	0.0	0.00E+00	
2.04E+01	0.0	0.00E+00		2.56E+01	0.0	0.00E+00	
1.94E+01	0.0	0.00E+00		2.43E+01	0.0	0.00E+00	

* End of operational period: 16 years







DATA SHEET 2 - aluminum

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	1683811		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	203,081	94,771
	1	123,180,548	57,484,256
Ore Stockpile East	0	430,781	80,413
	1	307,301,074	57,362,867
Ore Stockpile Southwest	0	N/A	953,397
	1	N/A	102,776,959
Tailings Facility	0	203,081	94,771
	1	123,180,548	57,484,256
ROM Ore Stockpiles	0	N/A	10,901,279
	1	N/A	133,620,011
Pit to Dipeta	0	2,494,173	3,897,117
	1	74,647,362	116,636,475
Pit to Mofia	0	N/A	15,028,949
	1	N/A	252,398,824

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	8612.50087	74175171.3	203080.5511
	b	3658.47	5355.45	Scenario 2	5883.45816	34615079.94	94770.92386
	c	-33676220	-33676220				
Full Contribution	a	0.03	0.06	Scenario 1	212112.46	44,991,694,996	123,180,548
	b	-3658.47	-5355.45	Scenario 2	144900.39	20,996,124,331	57,484,256
	c	-538819520	-538819520				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	12543.6394	157,342,891	430,781
	b	2524.35	5842.73	Scenario 2	5419.47164	29,370,673	80,413
	c	-33676220	-33676220				
Full Contribution	a	0.01	0.07	Scenario 1	335024.95	112,241,717,165	307,301,074
	b	-2524.35	-5842.73	Scenario 2	144747.32	20,951,787,204	57,362,867
	c	-589333850	-589333850				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	5840.76	Scenario 2	18660.873	348,228,181	953,397
	c	-126285825	-126285825				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-5840.76	Scenario 2	193750.572	37,539,284,190	102,776,959
	c	-732457785	-732457785				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	8612.500874	74,175,171	203,081
	b	3658.47	5355.45	Scenario 2	5883.458162	34,615,080	94,771
	c	-33676220	-33676220				
Full Contribution	a	0.03	0.06	Scenario 1	212112.4584	44,991,694,996	123,180,548
	b	-3658.47	-5355.45	Scenario 2	144900.3945	20,996,124,331	57,484,256
	c	-5.39E+08	-538819520				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	7540.39	Scenario 2	63100.64981	3,981,692,006	10,901,279
	c	-6.74E+08	-673524400				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-7540.39	Scenario 2	220917.8782	48,804,708,893	133,620,011
	c	-7.58E+08	-757714950				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	30182.41965	910,978,456	2,494,173
	b	10846.02	8676.81	Scenario 2	37728.02456	1,423,403,837	3,897,117
	c	-4.21E+08	-420952750				
Full Contribution	a	0.10	0.07	Scenario 1	165120.96	27,264,930,762	74,647,362
	b	-10846.02	-8676.81	Scenario 2	206401.20	42,601,454,315	116,636,475
	c	-1.01E+09	-1010286600				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	8318.52	Scenario 2	74089.84774	5,489,305,538	15,028,949
	c	-841905500	-841905500				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-10846.02	-8318.52	Scenario 2	303625.84	92,188,652,250	252,398,824
	c	-1262858250	-1262858250				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

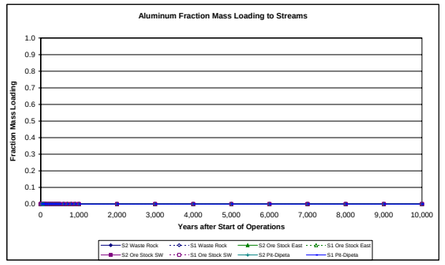
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Max Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

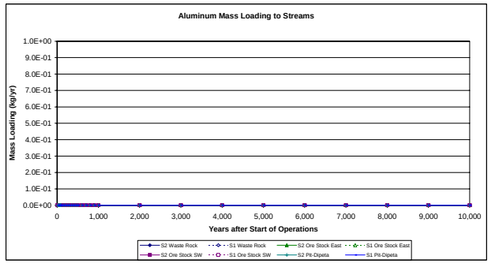
Loading Calculations to Kasana (kg/year)

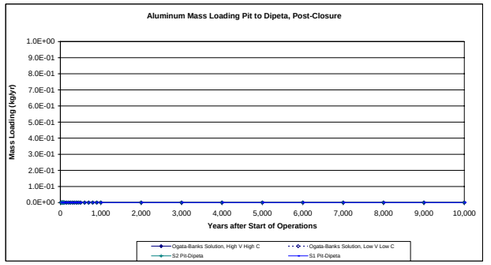
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Ogata-Banks Solution, High V High C: Post-closure Loading to Dipeta, Scenario 1 (kg/yr)			Ogata-Banks Solution, Low V Low C: Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)	Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
2.18E+03	0.0	0.00E+00	2.73E+03	0.0	0.00E+00
1.54E+03	0.0	0.00E+00	1.93E+03	0.0	0.00E+00
1.26E+03	0.0	0.00E+00	1.58E+03	0.0	0.00E+00
1.09E+03	0.0	0.00E+00	1.37E+03	0.0	0.00E+00
9.77E+02	0.0	0.00E+00	1.22E+03	0.0	0.00E+00
6.91E+02	0.0	0.00E+00	8.63E+02	0.0	0.00E+00
5.64E+02	0.0	0.00E+00	7.05E+02	0.0	0.00E+00
4.88E+02	0.0	0.00E+00	6.11E+02	0.0	0.00E+00
4.37E+02	0.0	0.00E+00	5.46E+02	0.0	0.00E+00
3.99E+02	0.0	0.00E+00	4.98E+02	0.0	0.00E+00
3.69E+02	0.0	0.00E+00	4.61E+02	0.0	0.00E+00
3.45E+02	0.0	0.00E+00	4.32E+02	0.0	0.00E+00
3.26E+02	0.0	0.00E+00	4.07E+02	0.0	0.00E+00
2.95E+02	0.0	0.00E+00	3.68E+02	0.0	0.00E+00
2.71E+02	0.0	0.00E+00	3.39E+02	0.0	0.00E+00
2.52E+02	0.0	0.00E+00	3.15E+02	0.0	0.00E+00
2.37E+02	0.0	0.00E+00	2.96E+02	0.0	0.00E+00
2.24E+02	0.0	0.00E+00	2.80E+02	0.0	0.00E+00
1.56E+02	0.0	0.00E+00	1.96E+02	0.0	0.00E+00
1.27E+02	0.0	0.00E+00	1.59E+02	0.0	0.00E+00
1.10E+02	0.0	0.00E+00	1.37E+02	0.0	0.00E+00
9.81E+01	0.0	0.00E+00	1.23E+02	0.0	0.00E+00
8.95E+01	0.0	0.00E+00	1.12E+02	0.0	0.00E+00
8.28E+01	0.0	0.00E+00	1.04E+02	0.0	0.00E+00
7.74E+01	0.0	0.00E+00	9.68E+01	0.0	0.00E+00
7.30E+01	0.0	0.00E+00	9.12E+01	0.0	0.00E+00
6.92E+01	0.0	0.00E+00	8.65E+01	0.0	0.00E+00

* End of operational period: 16 years







DATA SHEET 3 - silver

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	192		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	23	11
	1	14,031	6,548
Ore Stockpile East	0	49	9
	1	35,004	6,534
Ore Stockpile Southwest	0	N/A	109
	1	N/A	11,707
Tailings Facility	0	23	11
	1	14,031	6,548
ROM Ore Stockpiles	0	N/A	1,242
	1	N/A	15,220
Pit to Dipeta	0	334	494
	1	8,553	13,336
Pit to Mofia	0	N/A	1,762
	1	N/A	28,800

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	91.9193425	8449.165527	23.1325545
	b	39.05	57.16	Scenario 2	62.7928651	3942.943913	10.7951921
	c	-3836	-3836				
Full Contribution	a	0.03	0.06	Scenario 1	2263.83	5,124.926	14.031
	b	-39.05	-57.16	Scenario 2	1546.49	2,391,632	6,548
	c	-61376	-61376				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	133.875527	17,923	49
	b	26.94	62.36	Scenario 2	57.8408383	3,346	9
	c	-3836	-3836				
Full Contribution	a	0.01	0.07	Scenario 1	3575.65	12,785,260	35,004
	b	-26.94	-62.36	Scenario 2	1544.86	2,386,582	6,534
	c	-67130	-67130				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	62.34	Scenario 2	199.163425	39,666	109
	c	-14385	-14385				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-62.34	Scenario 2	2067.85758	4,276,035	11,707
	c	-83433	-83433				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	91.91934	8,449	23
	b	39.05	57.16	Scenario 2	62.79287	3,943	11
	c	-3836	-3836				
Full Contrib	a	0.03	0.06	Scenario 1	2263.83	5,124.926	14.031
	b	-39.05	-57.16	Scenario 2	1546.49	2,391,632	6,548
	c	-61376	-61376				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	80.48	Scenario 2	673.4595	453,548	1,242
	c	-76720	-76720				
Full Contrib	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-80.48	Scenario 2	2357.808	5,559,260	15,220
	c	-86310	-86310				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	322.1304	103,768	334
	b	115.76	92.61	Scenario 2	402.663	162,137	494
	c	-47950	-47950				
Full Contrib	a	0.10	0.07	Scenario 1	1762.30	3,105,701	8,553
	b	-115.76	-92.61	Scenario 2	2202.87	4,852,658	13,336
	c	-115080	-115080				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	88.78	Scenario 2	790.7448	625,277	1,762
	c	-95900	-95900				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-115.76	-88.78	Scenario 2	3240.53	10,501,050	28,800
	c	-143850	-143850				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	1.29E-04	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			7.96E-04	1.05E-03	0.00E+00	7.96E-04	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.41E-03	1.66E-03	0.00E+00	1.41E-03	0.00E+00	0.00E+00	0.00E+00
30	4.90E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.94E-03	3.19E-03	0.00E+00	2.94E-03	0.00E+00	0.00E+00	0.00E+00
40	1.20E-03	0.00E+00	0.00E+00	1.20E-03	0.00E+00	0.00E+00	0.00E+00	4.47E-03	4.73E-03	0.00E+00	4.47E-03	0.00E+00	0.00E+00	0.00E+00
50	1.92E-03	2.66E-05	0.00E+00	1.92E-03	0.00E+00	0.00E+00	0.00E+00	6.00E-03	6.26E-03	0.00E+00	6.00E-03	0.00E+00	0.00E+00	0.00E+00
60	2.63E-03	3.13E-04	0.00E+00	2.63E-03	0.00E+00	0.00E+00	0.00E+00	7.53E-03	7.79E-03	0.00E+00	7.53E-03	0.00E+00	0.00E+00	0.00E+00
70	3.35E-03	5.99E-04	0.00E+00	3.35E-03	0.00E+00	0.00E+00	0.00E+00	9.06E-03	9.32E-03	0.00E+00	9.06E-03	0.00E+00	0.00E+00	0.00E+00
80	4.06E-03	8.85E-04	0.00E+00	4.06E-03	0.00E+00	0.00E+00	0.00E+00	1.06E-02	1.09E-02	0.00E+00	1.06E-02	0.00E+00	0.00E+00	0.00E+00
90	4.77E-03	1.17E-03	0.00E+00	4.77E-03	0.00E+00	0.00E+00	0.00E+00	1.21E-02	1.24E-02	0.00E+00	1.21E-02	0.00E+00	0.00E+00	0.00E+00
100	5.49E-03	1.46E-03	0.00E+00	5.49E-03	0.00E+00	0.00E+00	0.00E+00	1.36E-02	1.39E-02	0.00E+00	1.36E-02	0.00E+00	0.00E+00	0.00E+00
150	9.06E-03	2.89E-03	0.00E+00	9.06E-03	0.00E+00	0.00E+00	0.00E+00	2.13E-02	2.16E-02	3.57E-03	2.13E-02	0.00E+00	0.00E+00	0.00E+00
200	1.26E-02	4.32E-03	0.00E+00	1.26E-02	0.00E+00	0.00E+00	0.00E+00	2.89E-02	2.92E-02	7.88E-03	2.89E-02	0.00E+00	0.00E+00	0.00E+00
250	1.62E-02	5.75E-03	0.00E+00	1.62E-02	0.00E+00	0.00E+00	0.00E+00	3.66E-02	3.69E-02	1.22E-02	3.66E-02	0.00E+00	0.00E+00	0.00E+00
300	1.98E-02	7.18E-03	0.00E+00	1.98E-02	0.00E+00	0.00E+00	0.00E+00	4.42E-02	4.46E-02	1.65E-02	4.42E-02	0.00E+00	0.00E+00	0.00E+00
350	2.33E-02	8.61E-03	0.00E+00	2.33E-02	0.00E+00	0.00E+00	0.00E+00	5.19E-02	5.22E-02	2.08E-02	5.19E-02	0.00E+00	0.00E+00	0.00E+00
400	2.69E-02	1.00E-02	0.00E+00	2.69E-02	0.00E+00	1.93E-03	0.00E+00	5.95E-02	5.99E-02	2.51E-02	5.95E-02	0.00E+00	0.00E+00	0.00E+00
450	3.05E-02	1.15E-02	0.00E+00	3.05E-02	0.00E+00	8.02E-03	0.00E+00	6.72E-02	6.76E-02	2.94E-02	6.72E-02	0.00E+00	0.00E+00	0.00E+00
500	3.40E-02	1.29E-02	0.00E+00	3.40E-02	0.00E+00	1.41E-02	0.00E+00	7.48E-02	7.52E-02	3.37E-02	7.48E-02	0.00E+00	0.00E+00	0.00E+00
600	4.12E-02	1.58E-02	0.00E+00	4.12E-02	0.00E+00	2.63E-02	0.00E+00	9.01E-02	9.06E-02	4.24E-02	9.01E-02	0.00E+00	0.00E+00	0.00E+00
700	4.83E-02	1.86E-02	0.00E+00	4.83E-02	0.00E+00	3.84E-02	0.00E+00	1.05E-01	1.06E-01	5.10E-02	1.05E-01	0.00E+00	0.00E+00	0.00E+00
800	5.55E-02	2.15E-02	0.00E+00	5.55E-02	0.00E+00	5.06E-02	0.00E+00	1.21E-01	1.21E-01	5.96E-02	1.21E-01	0.00E+00	0.00E+00	0.00E+00
900	6.26E-02	2.43E-02	0.00E+00	6.26E-02	0.00E+00	6.28E-02	0.00E+00	1.36E-01	1.37E-01	6.82E-02	1.36E-01	0.00E+00	0.00E+00	0.00E+00
1,000	6.97E-02	2.72E-02	0.00E+00	6.97E-02	0.00E+00	7.49E-02	0.00E+00	1.51E-01	1.52E-01	7.69E-02	1.51E-01	0.00E+00	0.00E+00	0.00E+00
2,000	1.41E-01	5.58E-02	0.00E+00	1.41E-01	0.00E+00	1.97E-01	0.00E+00	3.04E-01	3.05E-01	1.63E-01	3.04E-01	5.42E-02	1.13E-01	6.96E-03
3,000	2.13E-01	8.44E-02	0.00E+00	2.13E-01	0.00E+00	3.18E-01	0.00E+00	4.57E-01	4.58E-01	2.49E-01	4.57E-01	1.26E-01	1.91E-01	4.39E-02
4,000	2.84E-01	1.13E-01	0.00E+00	2.84E-01	0.00E+00	4.40E-01	0.00E+00	6.10E-01	6.12E-01	3.36E-01	6.10E-01	1.97E-01	2.69E-01	8.09E-02
5,000	3.55E-01	1.42E-01	0.00E+00	3.55E-01	0.00E+00	5.62E-01	0.00E+00	7.63E-01	7.65E-01	4.22E-01	7.63E-01	2.69E-01	3.47E-01	1.18E-01
6,000	4.27E-01	1.70E-01	0.00E+00	4.27E-01	0.00E+00	6.83E-01	0.00E+00	9.16E-01	9.18E-01	5.08E-01	9.16E-01	3.40E-01	4.25E-01	1.55E-01
7,000	4.98E-01	1.99E-01	0.00E+00	4.98E-01	0.00E+00	8.05E-01	0.00E+00	1.06E+00	1.06E+00	5.94E-01	1.06E+00	4.12E-01	5.03E-01	1.92E-01
8,000	5.69E-01	2.27E-01	0.00E+00	5.69E-01	0.00E+00	9.27E-01	0.00E+00	1.00E+00	1.00E+00	6.80E-01	1.00E+00	4.83E-01	5.81E-01	2.29E-01
9,000	6.41E-01	2.56E-01	0.00E+00	6.41E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	7.67E-01	1.00E+00	5.55E-01	6.58E-01	2.66E-01
10,000	7.12E-01	2.85E-01	0.00E+00	7.12E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	8.53E-01	1.00E+00	6.27E-01	7.36E-01	3.03E-01

Time from Start of Operations (Years)*	Loading Calculations to Kasana (kg/year): Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	9.44E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	4.01E-03	0.00E+00	7.68E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	4.75E-03	0.00E+00	7.68E-04	0.00E+00	0.00E+00	0.00E+00	2.82E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	9.52E-03	1.62E-04	1.43E-03	0.00E+00	0.00E+00	0.00E+00	5.88E-10	9.81E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	1.51E-02	3.97E-04	2.12E-03	0.00E+00	0.00E+00	0.00E+00	8.94E-10	2.41E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	2.02E-02	6.33E-04	2.81E-03	3.73E-06	0.00E+00	0.00E+00	1.20E-09	3.84E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	2.54E-02	8.69E-04	3.49E-03	4.38E-05	0.00E+00	0.00E+00	1.51E-09	5.27E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	3.06E-02	1.10E-03	4.18E-03	8.39E-05	0.00E+00	0.00E+00	1.81E-09	6.70E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	3.57E-02	1.34E-03	4.87E-03	1.24E-04	0.00E+00	0.00E+00	2.12E-09	8.12E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	4.09E-02	1.58E-03	5.55E-03	1.64E-04	0.00E+00	0.00E+00	2.42E-09	9.55E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	4.61E-02	1.81E-03	6.24E-03	2.04E-04	0.00E+00	0.00E+00	2.73E-09	1.10E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	7.19E-02	2.99E-03	9.68E-03	4.05E-04	8.00E-04	0.00E+00	4.26E-09	1.81E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	9.77E-02	4.17E-03	1.31E-02	6.05E-04	1.77E-03	0.00E+00	5.79E-09	2.53E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	1.24E-01	5.35E-03	1.65E-02	8.05E-04	2.73E-03	0.00E+00	7.32E-09	3.24E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	1.49E-01	6.52E-03	2.00E-02	1.01E-03	3.70E-03	0.00E+00	8.85E-09	3.96E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	1.75E-01	7.70E-03	2.34E-02	1.21E-03	4.67E-03	0.00E+00	1.04E-08	4.67E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	2.01E-01	8.88E-03	2.69E-02	1.41E-03	5.63E-03	0.00E+00	1.19E-08	5.38E-09	0.00E+00	0.00E+00	7.42E-02	0.00E+00	0.00E+00	0.00E+00
450	2.27E-01	1.01E-02	3.03E-02	1.61E-03	6.60E-03	0.00E+00	1.34E-08	6.10E-09	0.00E+00	0.00E+00	3.08E-01	0.00E+00	0.00E+00	0.00E+00
500	2.53E-01	1.12E-02	3.37E-02	1.81E-03	7.56E-03	0.00E+00	1.50E-08	6.81E-09	0.00E+00	0.00E+00	5.41E-01	0.00E+00	0.00E+00	0.00E+00
600	3.04E-01	1.36E-02	4.06E-02	2.21E-03	9.50E-03	0.00E+00	1.80E-08	8.24E-09	0.00E+00	0.00E+00	1.01E+00	8.85E-03	0.00E+00	0.00E+00
700	3.56E-01	1.60E-02	4.75E-02	2.61E-03	1.14E-02	0.00E+00	2.11E-08	9.67E-09	0.00E+00	0.00E+00	1.47E+00	2.46E-02	0.00E+00	0.00E+00
800	4.08E-01	1.83E-02	5.43E-02	3.01E-03	1.34E-02	0.00E+00	2.42E-08	1.11E-08	0.00E+00	0.00E+00	1.94E+00	4.04E-02	0.00E+00	0.00E+00
900	4.59E-01	2.07E-02	6.12E-02	3.41E-03	1.53E-02	0.00E+00	2.72E-08	1.25E-08	0.00E+00	0.00E+00	2.41E+00	5.62E-02	0.00E+00	0.00E+00
1,000	5.11E-01	2.30E-02	6.81E-02	3.81E-03	1.72E-02	0.00E+00	3.03E-08	1.40E-08	0.00E+00	0.00E+00	2.87E+00	7.20E-02	0.00E+00	0.00E+00
2,000	1.03E+00	4.66E-02	1.37E-01	7.82E-03	3.66E-02	0.00E+00	6.09E-08	2.82E-08	0.00E+00	0.00E+00	7.54E+00	2.30E-01	4.70E-02	1.41E-02
3,000	1.54E+00	7.02E-02	2.05E-01	1.18E-02	5.59E-02	0.00E+00	9.15E-08	4.25E-08	0.00E+00	0.00E+00	1.22E+01	3.88E-01	2.97E-01	8.91E-02
4,000	2.06E+00	9.37E-02	2.74E-01	1.58E-02	7.52E-02	0.00E+00	1.22E-07	5.68E-08	0.00E+00	0.00E+00	1.69E+01	5.46E-01	5.47E-01	1.64E-01
5,000	2.58E+00	1.17E-01	3.43E-01	1.98E-02	9.45E-02	0.00E+00	1.53E-07	7.11E-08	0.00E+00	0.00E+00	2.15E+01	7.03E-01	7.97E-01	2.39E-01
6,000	3.09E+00	1.41E-01	4.12E-01	2.39E-02	1.14E-01	0.00E+00	1.83E-07	8.54E-08	0.00E+00	0.00E+00	2.62E+01	8.61E-01	1.05E+00	3.14E-01
7,000	3.38E+00	1.64E-01	4.48E-01	2.79E-02	1.33E-01	0.00E+00	2.00E-07	9.97E-08	0.00E+00	0.00E+00	3.09E+01	1.02E+00	1.30E+00	3.89E-01
8,000	3.38E+00	1.88E-01	4.48E-01	3.19E-02	1.53E-01	0.00E+00	2.00E-07	1.14E-07	0.00E+00	0.00E+00	3.55E+01	1.18E+00	1.55E+00	4.64E-01
9,000	3.38E+00	2.12E-01	4.48E-01	3.59E-02	1.72E-01	0.00E+00	2.00E-07	1.28E-07	0.00E+00	0.00E+00	3.84E+01	1.33E+00	1.80E+00	5.39E-01
10,000	3.38E+00	2.35E-01	4.48E-01	3.99E-02	1.91E-01	0.00E+00	2.00E-07	1.43E-07	0.00E+00	0.00E+00	3.84E+01	1.49E+00	2.05E+00	6.14E-01

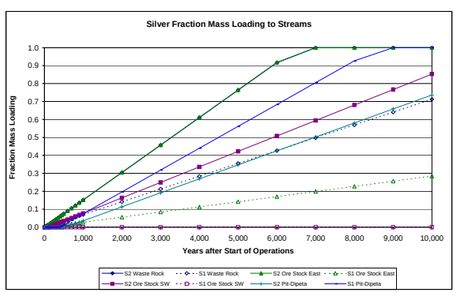
Ogata-Banks Solution, High V High C

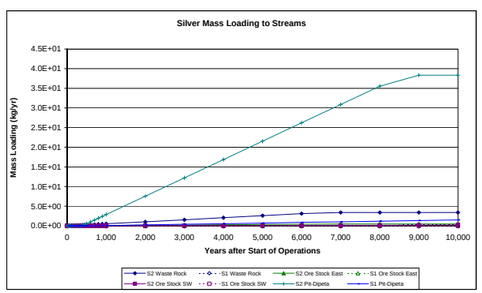
Post-closure Loading to Dipeta, Scenario 1 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0
N/A	N/A	0
N/A	N/A	0
N/A	N/A	0
2.32E+01	0.0	0.00E+00
1.63E+01	0.0	0.00E+00
1.33E+01	0.0	0.00E+00
1.14E+01	0.0	0.00E+00
1.02E+01	0.0	0.00E+00
7.03E+00	0.0	0.00E+00
5.60E+00	0.0	0.00E+00
4.73E+00	0.0	0.00E+00
4.13E+00	0.0	0.00E+00
3.67E+00	0.0	0.00E+00
3.31E+00	0.0	0.00E+00
3.01E+00	0.0	0.00E+00
2.76E+00	0.0	0.00E+00
2.35E+00	0.0	0.00E+00
2.03E+00	0.0	0.00E+00
1.76E+00	0.0	2.43E-01
1.54E+00	0.0	5.66E-01
1.35E+00	0.1	1.09E+00
1.71E-01	0.8	1.55E+01
-4.86E-01	1.5	2.89E+01
-9.60E-01	1.8	3.50E+01
-1.34E+00	1.9	3.72E+01
-1.66E+00	2.0	3.80E+01
-1.94E+00	2.0	3.82E+01
-2.20E+00	2.0	3.84E+01
-2.43E+00	2.0	3.84E+01
-2.65E+00	2.0	3.84E+01

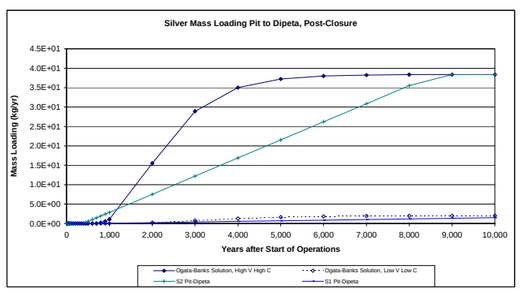
Ogata-Banks Solution, Low V Low C

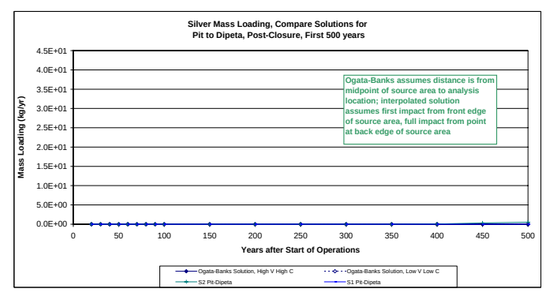
Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0
N/A	N/A	0
N/A	N/A	0
N/A	N/A	0
2.91E+01	0.0	0.00E+00
2.05E+01	0.0	0.00E+00
1.67E+01	0.0	0.00E+00
1.44E+01	0.0	0.00E+00
1.28E+01	0.0	0.00E+00
8.94E+00	0.0	0.00E+00
7.19E+00	0.0	0.00E+00
6.13E+00	0.0	0.00E+00
5.40E+00	0.0	0.00E+00
4.85E+00	0.0	0.00E+00
4.42E+00	0.0	0.00E+00
4.06E+00	0.0	0.00E+00
3.77E+00	0.0	0.00E+00
3.29E+00	0.0	0.00E+00
2.92E+00	0.0	0.00E+00
2.62E+00	0.0	0.00E+00
2.37E+00	0.0	0.00E+00
2.15E+00	0.0	0.00E+00
8.88E-01	0.2	2.12E-01
2.22E-01	0.8	7.64E-01
-2.40E-01	1.3	1.28E+00
-6.00E-01	1.6	1.63E+00
-9.00E-01	1.8	1.82E+00
-1.16E+00	1.9	1.92E+00
-1.39E+00	2.0	1.98E+00
-1.59E+00	2.0	2.00E+00
-1.78E+00	2.0	2.02E+00

* End of operational period: 16 years









DATA SHEET 4 - beryllium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	66781		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	8,054	3,759
	1	4,885,418	2,279,862
Ore Stockpile East	0	17,085	3,189
	1	12,187,753	2,275,047
Ore Stockpile Southwest	0	N/A	37,812
	1	N/A	4,076,199
Tailings Facility	0	8,054	3,759
	1	4,885,418	2,279,862
ROM Ore Stockpiles	0	N/A	432,352
	1	N/A	5,299,453
Pit to Dipeta	0	98,968	154,610
	1	2,960,609	4,625,924
Pit to Mofia	0	N/A	596,106
	1	N/A	10,010,344

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	1715.17748	2941833.801	8054.30199
	b	728.58	1066.54	Scenario 2	1171.68928	1372855.774	3758.67426
	c	-1335620	-1335620				
Full Contribution	a	0.03	0.06	Scenario 1	42242.15	1,784,398,833	4,885,418
	b	-728.58	-1066.54	Scenario 2	28856.88	832,719,455	2,279,862
	c	-21369920	-21369920				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	2498.06279	6,240,318	17,085
	b	502.72	1163.58	Scenario 2	1079.28648	1,164,859	3,189
	c	-1335620	-1335620				
Full Contribution	a	0.01	0.07	Scenario 1	66720.14	4,451,576,878	12,187,753
	b	-502.72	-1163.58	Scenario 2	28826.39	830,961,017	2,275,047
	c	-23373350	-23373350				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	1163.19	Scenario 2	3716.30838	13,810,948	37,812
	c	-5008575	-5008575				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-1163.19	Scenario 2	38585.38	1,488,831,548	4,076,199
	c	-29049735	-29049735				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	1715.177	2,941,834	8,054
	b	728.58	1066.54	Scenario 2	1171.689	1,372,856	3,759
	c	-1335620	-1335620				
Full Contribution	a	0.03	0.06	Scenario 1	42242.15	1,784,398,833	4,885,418
	b	-728.58	-1066.54	Scenario 2	28856.88	832,719,455	2,279,862
	c	-21369920	-21369920				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	1501.67	Scenario 2	12566.48	157,916,401	432,352
	c	-26712400	-26712400				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-1501.67	Scenario 2	43995.74	1,935,625,355	5,299,453
	c	-30051450	-30051450				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	6010.822	36,129,977	98,968
	b	2159.98	1727.99	Scenario 2	7513.527	56,453,089	154,610
	c	-16695250	-16695250				
Full Contribution	a	0.10	0.07	Scenario 1	32883.80	1,081,344,249	2,960,609
	b	-2159.98	-1727.99	Scenario 2	41104.75	1,689,600,389	4,625,924
	c	-40068600	-40068600				

Pit to Mofia, Post-closure

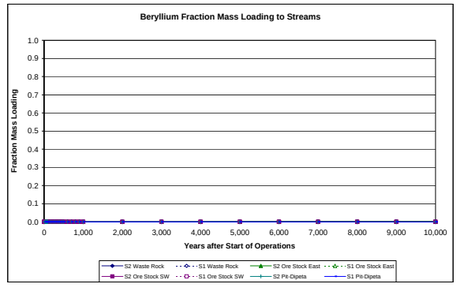
	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	1656.63	Scenario 2	14754.98	217,709,299	596,106
	c	-33390500	-33390500				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-2159.98	-1656.63	Scenario 2	60467.01	3,656,259,750	10,010,344
	c	-50085750	-50085750				

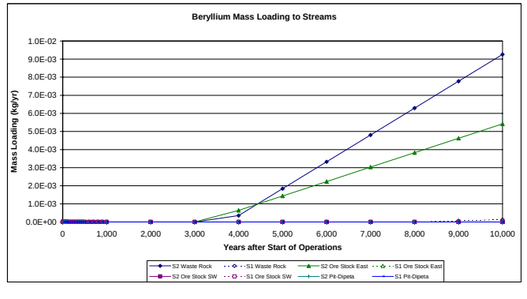
a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

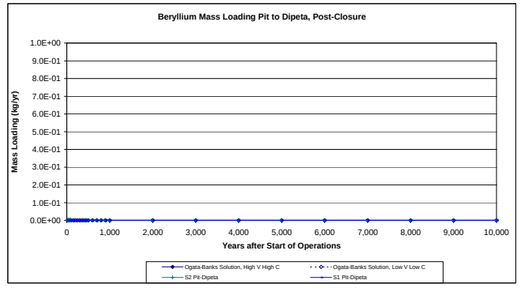
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading	Loading Calculations to Kasana (kg/year): Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-04	3.57E-04	0.00E+00	1.06E-04	0.00E+00	0.00E+00	0.00E+00	3.58E-04	0.00E+00	6.45E-04	0.00E+00	0.00E+00	0.00E+00	2.48E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.45E-04	7.97E-04	0.00E+00	5.45E-04	0.00E+00	0.00E+00	0.00E+00	1.84E-03	0.00E+00	1.44E-03	0.00E+00	0.00E+00	0.00E+00	1.28E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.85E-04	1.24E-03	0.00E+00	9.85E-04	0.00E+00	0.00E+00	0.00E+00	3.32E-03	0.00E+00	2.24E-03	0.00E+00	0.00E+00	0.00E+00	2.31E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-03	1.68E-03	0.00E+00	1.42E-03	0.00E+00	0.00E+00	0.00E+00	4.81E-03	0.00E+00	3.03E-03	0.00E+00	0.00E+00	0.00E+00	3.33E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.86E-03	2.12E-03	0.00E+00	1.86E-03	0.00E+00	0.00E+00	0.00E+00	6.29E-03	0.00E+00	3.83E-03	0.00E+00	0.00E+00	0.00E+00	4.36E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9,000	1.94E-04	0.00E+00	0.00E+00	1.94E-04	0.00E+00	0.00E+00	0.00E+00	2.30E-03	2.56E-03	0.00E+00	2.30E-03	0.00E+00	0.00E+00	0.00E+00	7.77E-03	6.40E-05	4.62E-03	0.00E+00	0.00E+00	0.00E+00	5.39E-10	3.88E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10,000	3.99E-04	0.00E+00	0.00E+00	3.99E-04	0.00E+00	0.00E+00	0.00E+00	2.74E-03	3.00E-03	0.00E+00	2.74E-03	0.00E+00	0.00E+00	0.00E+00	9.26E-03	1.32E-04	5.42E-03	0.00E+00	0.00E+00	0.00E+00	6.42E-10	7.98E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

* End of operational period: 16 years

Ogata-Banks Solution, High V High C: Post-closure Loading to Dipeta, Scenario 1 (kg/yr)				Ogata-Banks Solution, Low V Low C: Post-closure Loading to Dipeta, Scenario 2 (kg/yr)			
Beta	erfc (Beta)		Mass Loading (kg/yr)	Beta	erfc (Beta)		Mass Loading (kg/yr)
N/A	N/A		0	N/A	N/A		0
N/A	N/A		0	N/A	N/A		0
N/A	N/A		0	N/A	N/A		0
N/A	N/A		0	N/A	N/A		0
4.35E+02	0.0	0.00E+00		5.44E+02	0.0	0.00E+00	
3.08E+02	0.0	0.00E+00		3.84E+02	0.0	0.00E+00	
2.51E+02	0.0	0.00E+00		3.14E+02	0.0	0.00E+00	
2.17E+02	0.0	0.00E+00		2.72E+02	0.0	0.00E+00	
1.95E+02	0.0	0.00E+00		2.43E+02	0.0	0.00E+00	
1.38E+02	0.0	0.00E+00		1.72E+02	0.0	0.00E+00	
1.12E+02	0.0	0.00E+00		1.40E+02	0.0	0.00E+00	
9.72E+01	0.0	0.00E+00		1.22E+02	0.0	0.00E+00	
8.70E+01	0.0	0.00E+00		1.09E+02	0.0	0.00E+00	
7.94E+01	0.0	0.00E+00		9.92E+01	0.0	0.00E+00	
7.35E+01	0.0	0.00E+00		9.19E+01	0.0	0.00E+00	
6.87E+01	0.0	0.00E+00		8.59E+01	0.0	0.00E+00	
6.48E+01	0.0	0.00E+00		8.10E+01	0.0	0.00E+00	
5.86E+01	0.0	0.00E+00		7.33E+01	0.0	0.00E+00	
5.39E+01	0.0	0.00E+00		6.74E+01	0.0	0.00E+00	
5.02E+01	0.0	0.00E+00		6.27E+01	0.0	0.00E+00	
4.71E+01	0.0	0.00E+00		5.89E+01	0.0	0.00E+00	
4.46E+01	0.0	0.00E+00		5.57E+01	0.0	0.00E+00	
3.11E+01	0.0	0.00E+00		3.89E+01	0.0	0.00E+00	
2.52E+01	0.0	0.00E+00		3.16E+01	0.0	0.00E+00	
2.18E+01	0.0	0.00E+00		2.73E+01	0.0	0.00E+00	
1.94E+01	0.0	0.00E+00		2.43E+01	0.0	0.00E+00	
1.77E+01	0.0	0.00E+00		2.22E+01	0.0	0.00E+00	
1.63E+01	0.0	0.00E+00		2.05E+01	0.0	0.00E+00	
1.53E+01	0.0	0.00E+00		1.92E+01	0.0	0.00E+00	
1.44E+01	0.0	0.00E+00		1.80E+01	0.0	0.00E+00	
1.36E+01	0.0	0.00E+00		1.71E+01	0.0	0.00E+00	







DATA SHEET 5 - antimony

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	287		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

# Years of Operation	16
Years to Pit Flow-Through	50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	35	16
	1	21,010	9,805
Ore Stockpile East	0	73	14
	1	52,415	9,784
Ore Stockpile Southwest	0	N/A	163
	1	N/A	17,530
Tailings Facility	0	35	16
	1	21,010	9,805
ROM Ore Stockpiles	0	N/A	1,859
	1	N/A	22,791
Pit to Dipeta	0	475	715
	1	12,782	19,944
Pit to Mofia	0	N/A	2,613
	1	N/A	43,101

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	112.479875	12651.722	34.638528
	b	47.78	69.94	Scenario 2	76.8383828	5904.1371	16.164646
	c	-5744	-5744				
Full Contribution	a	0.03	0.06	Scenario 1	2770.20	7,674,029	21,010
	b	-47.78	-69.94	Scenario 2	1892.41	3,581,214	9,805
	c	-91904	-91904				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	163.820825	26,837	73
	b	32.97	76.31	Scenario 2	70.7786859	5,010	14
	c	-5744	-5744				
Full Contribution	a	0.01	0.07	Scenario 1	4375.45	########	52,415
	b	-32.97	-76.31	Scenario 2	1890.41	3,573,651	9,784
	c	-100520	-100520				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	76.28	Scenario 2	243.712331	59,396	163
	c	-21540	-21540				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-76.28	Scenario 2	2530.39628	6,402,905	17,530
	c	-124932	-124932				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	112.4799	12,652	35
	b	47.78	69.94	Scenario 2	76.83838	5,904	16
	c	-5744	-5744				
Full Contrib	a	0.03	0.06	Scenario 1	2770.204	7,674,029	21,010
	b	-47.78	-69.94	Scenario 2	1892.409	3,581,214	9,805
	c	-91904	-91904				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	98.48	Scenario 2	824.099	679,139	1,859
	c	-114880	-114880				
Full Contrib	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-98.48	Scenario 2	2885.203	8,324,398	22,791
	c	-129240	-129240				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	394.1846	155,381	475
	b	141.65	113.32	Scenario 2	492.7307	242,784	715
	c	-71800	-71800				
Full Contrib	a	0.10	0.07	Scenario 1	2156.49	4,650,455	12,782
	b	-141.65	-113.32	Scenario 2	2695.61	7,266,337	19,944
	c	-172320	-172320				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	108.64	Scenario 2	967.6187	936,286	2,613
	c	-143600	-143600				
Full Contributio	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-141.65	-108.64	Scenario 2	3965.38	15,724,200	43,101
	c	-215400	-215400				

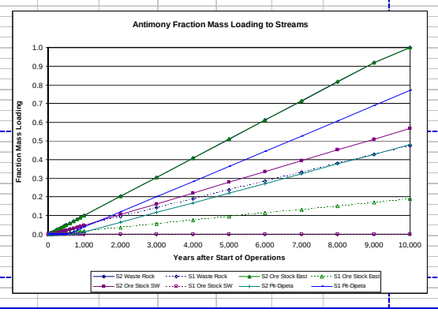
a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

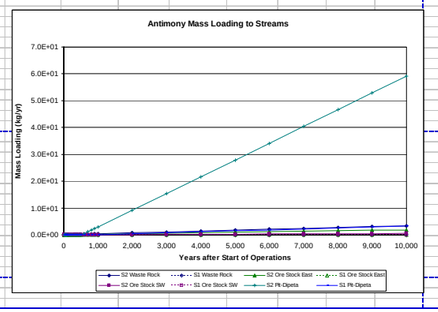
Loading Calculations to Kasana (kg/year)

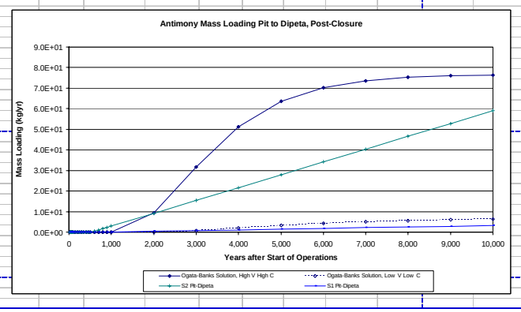
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00						
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00						
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	2.34E-04	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	6.91E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00						
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.92E-04	6.43E-04	0.00E+00	3.92E-04	0.00E+00	0.00E+00	0.00E+00	1.32E-03	0.00E+00	1.16E-03	0.00E+00	0.00E+00	0.00E+00	4.95E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.41E-03	1.67E-03	0.00E+00	1.41E-03	0.00E+00	0.00E+00	0.00E+00	4.77E-03	0.00E+00	3.01E-03	0.00E+00	0.00E+00	0.00E+00	1.79E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	2.56E-04	0.00E+00	0.00E+00	2.56E-04	0.00E+00	0.00E+00	0.00E+00	2.43E-03	2.69E-03	0.00E+00	2.43E-03	0.00E+00	0.00E+00	0.00E+00	8.22E-03	8.44E-05	4.86E-03	0.00E+00	0.00E+00	0.00E+00	3.08E-08	1.78E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	7.32E-04	0.00E+00	0.00E+00	7.32E-04	0.00E+00	0.00E+00	0.00E+00	3.46E-03	3.71E-03	0.00E+00	3.46E-03	0.00E+00	0.00E+00	0.00E+00	1.17E-02	2.42E-04	6.71E-03	0.00E+00	0.00E+00	0.00E+00	4.37E-08	5.10E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	1.21E-03	0.00E+00	0.00E+00	1.21E-03	0.00E+00	0.00E+00	0.00E+00	4.48E-03	4.74E-03	0.00E+00	4.48E-03	0.00E+00	0.00E+00	0.00E+00	1.51E-02	3.99E-04	8.56E-03	0.00E+00	0.00E+00	0.00E+00	5.66E-08	8.42E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	1.69E-03	0.00E+00	0.00E+00	1.69E-03	0.00E+00	0.00E+00	0.00E+00	5.50E-03	5.76E-03	0.00E+00	5.50E-03	0.00E+00	0.00E+00	0.00E+00	1.86E-02	5.56E-04	1.04E-02	0.00E+00	0.00E+00	0.00E+00	6.95E-08	1.17E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	2.16E-03	1.25E-04	0.00E+00	2.16E-03	0.00E+00	0.00E+00	0.00E+00	6.52E-03	6.78E-03	0.00E+00	6.52E-03	0.00E+00	0.00E+00	0.00E+00	2.20E-02	7.14E-04	1.23E-02	2.27E-05	0.00E+00	0.00E+00	8.24E-08	1.51E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	2.64E-03	3.16E-04	0.00E+00	2.64E-03	0.00E+00	0.00E+00	0.00E+00	7.54E-03	7.81E-03	0.00E+00	7.54E-03	0.00E+00	0.00E+00	0.00E+00	2.55E-02	8.71E-04	1.41E-02	5.75E-05	0.00E+00	0.00E+00	9.53E-08	1.84E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	3.12E-03	5.07E-04	0.00E+00	3.12E-03	0.00E+00	0.00E+00	0.00E+00	8.56E-03	8.83E-03	0.00E+00	8.56E-03	0.00E+00	0.00E+00	0.00E+00	2.89E-02	1.03E-03	1.60E-02	9.23E-05	0.00E+00	0.00E+00	1.08E-07	2.17E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	5.50E-03	1.46E-03	0.00E+00	5.50E-03	0.00E+00	0.00E+00	0.00E+00	1.37E-02	1.39E-02	0.00E+00	1.37E-02	0.00E+00	0.00E+00	0.00E+00	4.62E-02	1.82E-03	2.52E-02	2.66E-04	0.00E+00	0.00E+00	1.72E-07	3.83E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	7.88E-03	2.42E-03	0.00E+00	7.88E-03	0.00E+00	0.00E+00	0.00E+00	1.88E-02	1.91E-02	2.15E-03	1.88E-02	0.00E+00	0.00E+00	0.00E+00	6.34E-02	2.60E-03	3.45E-02	4.40E-04	1.95E-03	0.00E+00	2.37E-07	5.49E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	1.03E-02	3.37E-03	0.00E+00	1.03E-02	0.00E+00	0.00E+00	0.00E+00	2.39E-02	2.42E-02	5.03E-03	2.39E-02	0.00E+00	0.00E+00	0.00E+00	8.07E-02	3.39E-03	4.37E-02	6.14E-04	4.55E-03	0.00E+00	3.02E-07	7.15E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	1.27E-02	4.33E-03	0.00E+00	1.27E-02	0.00E+00	0.00E+00	0.00E+00	2.90E-02	2.93E-02	7.91E-03	2.90E-02	0.00E+00	0.00E+00	0.00E+00	9.79E-02	4.18E-03	5.30E-02	7.88E-04	7.15E-03	0.00E+00	3.66E-07	8.81E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	1.50E-02	5.29E-03	0.00E+00	1.50E-02	0.00E+00	0.00E+00	0.00E+00	3.41E-02	3.44E-02	1.08E-02	3.41E-02	0.00E+00	0.00E+00	0.00E+00	1.15E-01	4.96E-03	6.22E-02	9.62E-04	9.75E-03	0.00E+00	4.31E-07	1.05E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	1.74E-02	6.24E-03	0.00E+00	1.74E-02	0.00E+00	0.00E+00	0.00E+00	3.92E-02	3.95E-02	1.37E-02	3.92E-02	0.00E+00	0.00E+00	0.00E+00	1.32E-01	5.75E-03	7.15E-02	1.14E-03	1.24E-02	0.00E+00	4.95E-07	1.21E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	1.98E-02	7.19E-03	0.00E+00	1.98E-02	0.00E+00	0.00E+00	0.00E+00	4.43E-02	4.47E-02	1.65E-02	4.43E-02	0.00E+00	0.00E+00	0.00E+00	1.50E-01	6.54E-03	8.07E-02	1.31E-03	1.50E-02	0.00E+00	5.60E-07	1.38E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	2.22E-02	8.15E-03	0.00E+00	2.22E-02	0.00E+00	0.00E+00	0.00E+00	4.94E-02	4.98E-02	1.94E-02	4.94E-02	0.00E+00	0.00E+00	0.00E+00	1.67E-01	7.32E-03	9.00E-02	1.48E-03	1.76E-02	0.00E+00	6.24E-07	1.54E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	2.70E-02	1.01E-02	0.00E+00	2.70E-02	0.00E+00	6.09E-03	0.00E+00	5.96E-02	6.00E-02	2.52E-02	5.96E-02	0.00E+00	0.00E+00	0.00E+00	2.01E-01	8.90E-03	1.09E-01	1.83E-03	2.28E-02	0.00E+00	7.52E-07	1.88E-08	0.00E+00	0.00E+00	4.65E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	3.17E-02	1.20E-02	0.00E+00	3.17E-02	0.00E+00	1.42E-02	0.00E+00	6.99E-02	7.02E-02	3.09E-02	6.99E-02	0.00E+00	0.00E+00	0.00E+00	2.36E-01	1.05E-02	1.27E-01	2.18E-03	2.80E-02	0.00E+00	8.82E-07	2.21E-08	0.00E+00	0.00E+00	1.09E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	3.65E-02	1.39E-02	0.00E+00	3.65E-02	0.00E+00	2.23E-02	0.00E+00	8.01E-02	8.05E-02	3.67E-02	8.01E-02	0.00E+00	0.00E+00	0.00E+00	2.70E-01	1.20E-02	1.45E-01	2.53E-03	3.32E-02	0.00E+00	1.01E-06	2.54E-08	0.00E+00	0.00E+00	1.71E+00	1.24E-02	0.00E+00	0.00E+00	0.00E+00
900	4.13E-02	1.58E-02	0.00E+00	4.13E-02	0.00E+00	3.04E-02	0.00E+00	9.03E-02	9.07E-02	4.25E-02	9.03E-02	0.00E+00	0.00E+00	0.00E+00	3.05E-01	1.36E-02	1.64E-01	2.88E-03	3.84E-02	0.00E+00	1.14E-06	2.87E-08	0.00E+00	0.00E+00	2.33E+00	4.75E-02	0.00E+00	0.00E+00	0.00E+00
1,000	4.60E-02	1.77E-02	0.00E+00	4.60E-02	0.00E+00	3.86E-02	0.00E+00	1.01E-01	1.01E-01	4.82E-02	1.01E-01	0.00E+00	0.00E+00	0.00E+00	3.39E-01	1.52E-02	1.82E-01	3.22E-03	4.36E-02	0.00E+00	1.27E-06	3.20E-08	0.00E+00	0.00E+00	2.96E+00	8.27E-02	0.00E+00	0.00E+00	0.00E+00
2,000	9.37E-02	3.68E-02	0.00E+00	9.37E-02	0.00E+00	1.20E-01	0.00E+00	2.03E-01	2.03E-01	1.06E-01	2.03E-01	6.72E-03	6.42E-02	0.00E+00	6.84E-01	3.09E-02	3.67E-01	6.70E-03	9.56E-02	0.00E+00	2.56E-06	6.52E-08	0.00E+00	0.00E+00	9.19E+00	4.34E-01	0.00E+00	0.00E+00	8.80E-02
3,000	1.41E-01	5.59E-02	0.00E+00	1.41E-01	0.00E+00	2.01E-01	0.00E+00	3.05E-01	3.06E-01	1.63E-01	3.05E-01	5.45E-02	1.16E-01	8.31E-03	1.03E+00	4.67E-02	5.52E-01	1.02E-02	1.48E-01	0.00E+00	3.85E-06	9.84E-08	0.00E+00	0.00E+00	1.54E+01	7.85E-01	1.12E-01	5.62E-02	1.73E-01
4,000	1.89E-01	7.50E-02	0.00E+00	1.89E-01	0.00E+00	2.82E-01	0.00E+00	4.07E-01	4.08E-01	2.21E-01	4.07E-01	1.02E-01	1.68E-01	3.30E-02	1.37E+00	6.24E-02	7.37E-01	1.37E-02	2.00E-01	0.00E+00	5.14E-06	1.32E-07	0.00E+00	0.00E+00	2.17E+01	1.14E+00	4.46E-01	2.23E-01	3.46E-01
5,000	2.37E-01	9.41E-02	0.00E+00	2.37E-01	0.00E+00	3.64E-01	0.00E+00	5.09E-01	5.10E-01	2.79E-01	5.09E-01	1.50E-01	2.20E-01	5.77E-02	1.72E+00	7.81E-02	9.22E-01	1.71E-02	2.52E-01	0.00E+00	6.43E-06	1.65E-07	0.00E+00	0.00E+00	2.79E+01	1.49E+00	7.80E-01	3.90E-01	4.17E-01
6,000	2.84E-01	1.13E-01	0.00E+00	2.84E-01	0.00E+00	4.45E-01	0.00E+00	6.11E-01	6.13E-01	3.36E-01	6.11E-01	1.98E-01	2.72E-01	8.24E-02	2.06E+00	9.39E-02	1.11E+00	2.06E-02	3.04E-01	0.00E+00	7.72E-06	1.98E-07	0.00E+00	0.00E+00	3.41E+01	1.84E+00	1.11E+00	5.57E-01	5.01E-01
7,000	3.32E-01	1.32E-01	0.00E+00	3.32E-01	0.00E+00	5.26E-01	0.00E+00	7.13E-01	7.15E-01	3.94E-01	7.13E-01	2.46E-01	3.24E-01	1.07E-01	2.41E+00	1.10E-01	1.29E+00	2.41E-02	3.56E-01	0.00E+00	9.01E-06	2.31E-07	0.00E+00	0.00E+00	4.04E+01	2.19E+00	1.45E+00	7.24E-01	5.85E-01
8,000	3.80E-01	1.51E-01	0.00E+00	3.80E-01	0.00E+00	6.07E-01	0.00E+00	8.16E-01	8.17E-01	4.51E-01	8.16E-01	2.93E-01	3.76E-01	1.32E-01	2.75E+00	1.25E-01	1.48E+00	2.76E-02	4.08E-01	0.00E+00	1.03E-05	2.64E-07	0.00E+00	0.00E+00	4.66E+01	2.54E+00	1.78E+00	8.91E-01	6.69E-01
9,000	4.27E-01	1.71E-01	0.00E+00	4.27E-01	0.00E+00	6.89E-01	0.00E+00	9.18E-01	9.20E-01	5.09E-01	9.18E-01	3.41E-01	4.28E-01	1.57E-01	3.10E+00	1.41E-01	1.66E+00	3.11E-02	4.60E-01	0.00E+00	1.16E-05	2.98E-07	0.00E+00	0.00E+00	5.28E+01	2.89E+00	2.12E+00	1.06E+00	7.53E-01
10,000	4.75E-01	1.90E-01	0.00E+00	4.75E-01	0.00E+00	7.70E-01	0.00E+00	1.00E+00	1.00E+00	5.66E-01	1.00E+00	3.89E-01	4.80E-01	1.81E-01	3.38E+00	1.57E-01	1.81E+00	3.45E-02	5.12E-01	0.00E+00	1.26E-05	3.31E-07	0.00E+00	0.00E+00	5.91E+01	3.25E+00	2.45E+00	1.22E+00	8.38E-01

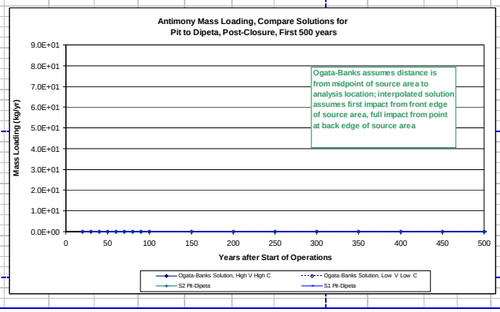
* End of operational period: 16 years

Ogata-Banks Solution, High V High C — Post-closure Loading to Dipeta, Scenario 1 (kg/yr)			Ogata-Banks Solution, Low V Low C — Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)	Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
2.84E+01	0.0	0.00E+00	3.56E+01	0.0	0.00E+00
2.00E+01	0.0	0.00E+00	2.51E+01	0.0	0.00E+00
1.63E+01	0.0	0.00E+00	2.05E+01	0.0	0.00E+00
1.41E+01	0.0	0.00E+00	1.77E+01	0.0	0.00E+00
1.26E+01	0.0	0.00E+00	1.58E+01	0.0	0.00E+00
8.74E+00	0.0	0.00E+00	1.11E+01	0.0	0.00E+00
7.03E+00	0.0	0.00E+00	8.94E+00	0.0	0.00E+00
5.99E+00	0.0	0.00E+00	7.66E+00	0.0	0.00E+00
5.27E+00	0.0	0.00E+00	6.78E+00	0.0	0.00E+00
4.73E+00	0.0	0.00E+00	6.13E+00	0.0	0.00E+00
4.30E+00	0.0	0.00E+00	5.61E+00	0.0	0.00E+00
3.96E+00	0.0	0.00E+00	5.19E+00	0.0	0.00E+00
3.66E+00	0.0	0.00E+00	4.84E+00	0.0	0.00E+00
3.20E+00	0.0	0.00E+00	4.29E+00	0.0	0.00E+00
2.83E+00	0.0	0.00E+00	3.86E+00	0.0	0.00E+00
2.53E+00	0.0	0.00E+00	3.51E+00	0.0	0.00E+00
2.29E+00	0.0	0.00E+00	3.22E+00	0.0	0.00E+00
2.07E+00	0.0	0.00E+00	2.97E+00	0.0	0.00E+00
8.18E-01	0.2	9.48E+00	1.57E+00	0.0	8.80E-02
1.55E-01	0.8	3.17E+01	8.71E-01	0.2	7.37E-01
-3.08E-01	1.3	5.13E+01	4.00E-01	0.6	1.93E+00
-6.69E-01	1.7	6.35E+01	4.17E-02	1.0	3.22E+00
-9.70E-01	1.8	7.02E+01	-2.50E-01	1.3	4.31E+00
-1.23E+00	1.9	7.36E+01	-4.97E-01	1.5	5.13E+00
-1.46E+00	2.0	7.52E+01	-7.14E-01	1.7	5.70E+00
-1.67E+00	2.0	7.60E+01	-9.07E-01	1.8	6.08E+00
-1.86E+00	2.0	7.64E+01	-1.08E+00	1.9	6.33E+00









DATA SHEET 6 - cobalt

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	421		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	51	24
	1	30,816	14,381
Ore Stockpile East	0	108	20
	1	76,877	14,350
Ore Stockpile Southwest	0	N/A	239
	1	N/A	25,712
Tailings Facility	0	51	24
	1	30,816	14,381
ROM Ore Stockpiles	0	N/A	2,727
	1	N/A	33,428
Pit to Dipeta	0	674	1,025
	1	18,724	29,229
Pit to Mofia	0	N/A	3,810
	1	N/A	63,192

Transport Parameters

Kasana Waste Rock

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	136.221564	18556.31459	50.8044205	
	b	57.86	84.71	Scenario 2	93.0570442	8659.613477	23.7087296	
	c	-8424.74	-8424.74					
Full Contribution	a	0.03	0.06	Scenario 1	3354.92	11,255,519	30,816	
	b	-57.86	-84.71	Scenario 2	2291.85	5,252,576	14,381	
	c	-134795.84	-134795.84					

Ore Stockpile East

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	198.399305	39.362	108	
	b	39.93	92.41	Scenario 2	85.7182967	7,348	20	
	c	-8424.74	-8424.74					
Full Contribution	a	0.01	0.07	Scenario 1	5299.00	28,079,377	76,877	
	b	-39.93	-92.41	Scenario 2	2289.43	5,241,484	14,350	
	c	-147432.95	-147432.95					

Ore Stockpile Southwest

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A	
	b	N/A	92.38	Scenario 2	295.15391	87,116	239	
	c	-31592.775	-31592.775					
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A	
	b	N/A	-92.38	Scenario 2	3064.49966	9,391,158	25,712	
	c	-183238.095	-183238.095					

Tailings Facility

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	136.2216	18,556	51	
	b	57.86	84.71	Scenario 2	93.05704	8,660	24	
	c	-8424.74	-8424.74					
Full Contribution	a	0.03	0.06	Scenario 1	3354.925	11,255,519	30,816	
	b	-57.86	-84.71	Scenario 2	2291.85	5,252,576	14,381	
	c	-134795.8	-134795.84					

ROM Ore Stockpiles

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A	
	b	N/A	119.26	Scenario 2	998.0457	996,095	2,727	
	c	-168494.8	-168494.8					
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A	
	b	N/A	-119.26	Scenario 2	3494.197	12,209,416	33,428	
	c	-189556.7	-189556.65					

Pit to Dipeta, Post-closure

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	477.3871	227,898	674	
	b	171.55	137.24	Scenario 2	596.7338	356,091	1,025	
	c	-105309.3	-105309.25					
Full Contribution	a	0.10	0.07	Scenario 1	2611.67	6,820,835	18,724	
	b	-171.55	-137.24	Scenario 2	3264.59	10,657,555	29,229	
	c	-252742.2	-252742.2					

Pit to Mofia, Post-closure

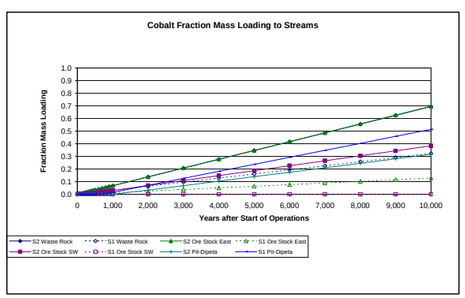
		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A	
	b	N/A	131.57	Scenario 2	1171.859	1,373,253	3,810	
	c	-210618.5	-210618.5					
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A	
	b	-171.55	-131.57	Scenario 2	4802.37	23,062,726	63,192	
	c	-315927.75	-315927.8					

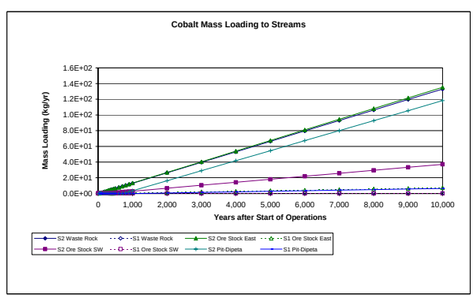
a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

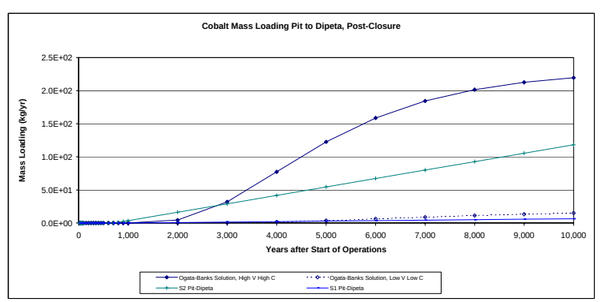
Time from Start of Operations (Years)*	Scenario 1 Kasana Waste Rock Fraction Mass Loading	Scenario 1 Ore Stock East Fraction Mass Loading	Scenario 1 Ore Stock SW Fraction Mass Loading	Scenario 1 Tailings Facility Fraction Mass Loading	Scenario 1 ROM Ore Stockpiles Fraction Mass	Scenario 1 Pit to Dipeta Fraction Mass Loading	Scenario 1 Pit to Mofia Fraction Mass Loading	Scenario 2 Kasana Waste Rock Fraction Mass Loading	Scenario 2 Ore Stock East Fraction Mass Loading	Scenario 2 Ore Stock SW Fraction Mass Loading	Scenario 2 Tailings Facility Fraction Mass Loading	Scenario 2 ROM Ore Stockpiles Fraction Mass	Scenario 2 Pit to Dipeta Fraction Mass Loading	Scenario 2 Pit to Mofia Fraction Mass Loading	Loading Calculations to Kasana (kg/year) Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Kasana Ore Stockpile East Max (S2, High C)	Kasana Ore Stockpile East Min (S1, Low C)	Kasana Ore Stockpile SW Max (S2, High C)	Kasana Ore Stockpile SW Min (S1, Low C)	Kasana Tailings Max (S2, High C)	Kasana Tailings Min (S1, Low C)	Kasana ROM Ore Max (S2, High C)	Kasana ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.38E-04	6.90E-04	0.00E+00	4.38E-04	7.00E+00	0.00E+00	0.00E+00	8.39E-02	0.00E+00	1.34E-01	0.00E+00	0.00E+00	4.07E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.13E-03	1.39E-03	0.00E+00	1.13E-03	0.00E+00	0.00E+00	0.00E+00	2.17E-01	0.00E+00	2.69E-01	0.00E+00	0.00E+00	1.05E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-03	2.09E-03	0.00E+00	1.83E-03	0.00E+00	0.00E+00	0.00E+00	3.50E-01	0.00E+00	4.05E-01	0.00E+00	0.00E+00	1.70E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	2.99E-04	0.00E+00	0.00E+00	2.99E-04	0.00E+00	0.00E+00	0.00E+00	2.53E-03	2.78E-03	0.00E+00	2.53E-03	0.00E+00	0.00E+00	0.00E+00	4.84E-01	2.19E-04	5.40E-01	0.00E+00	0.00E+00	2.35E-07	6.84E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	6.24E-04	0.00E+00	0.00E+00	6.24E-04	0.00E+00	0.00E+00	0.00E+00	3.22E-03	3.48E-03	0.00E+00	3.22E-03	0.00E+00	0.00E+00	0.00E+00	6.17E-01	4.57E-04	6.76E-01	0.00E+00	0.00E+00	2.99E-07	1.43E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	9.49E-04	0.00E+00	0.00E+00	9.49E-04	0.00E+00	0.00E+00	0.00E+00	3.92E-03	4.18E-03	0.00E+00	3.92E-03	0.00E+00	0.00E+00	0.00E+00	7.50E-01	6.95E-04	8.11E-01	0.00E+00	0.00E+00	3.64E-07	2.17E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	1.27E-03	0.00E+00	0.00E+00	1.27E-03	0.00E+00	0.00E+00	0.00E+00	4.62E-03	4.88E-03	0.00E+00	4.62E-03	0.00E+00	0.00E+00	0.00E+00	8.84E-01	9.33E-04	9.47E-01	0.00E+00	0.00E+00	4.29E-07	2.92E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	1.60E-03	0.00E+00	0.00E+00	1.60E-03	0.00E+00	0.00E+00	0.00E+00	5.31E-03	5.57E-03	0.00E+00	5.31E-03	0.00E+00	0.00E+00	0.00E+00	1.02E+00	1.17E-03	1.08E+00	0.00E+00	0.00E+00	4.93E-07	3.66E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	3.22E-03	5.50E-04	0.00E+00	3.22E-03	0.00E+00	0.00E+00	0.00E+00	8.80E-03	9.06E-03	0.00E+00	8.80E-03	0.00E+00	0.00E+00	0.00E+00	1.68E+00	2.36E-03	1.76E+00	3.10E-02	0.00E+00	8.17E-07	7.38E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	4.85E-03	1.20E-03	0.00E+00	4.85E-03	0.00E+00	0.00E+00	0.00E+00	1.23E-02	1.26E-02	0.00E+00	1.23E-02	0.00E+00	0.00E+00	0.00E+00	2.35E+00	3.55E-03	2.44E+00	6.78E-02	0.00E+00	1.14E-06	1.11E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	6.47E-03	1.85E-03	0.00E+00	6.47E-03	0.00E+00	0.00E+00	0.00E+00	1.58E-02	1.60E-02	4.51E-04	1.58E-02	0.00E+00	0.00E+00	0.00E+00	3.02E+00	4.74E-03	3.11E+00	1.05E-01	0.00E+00	1.46E-06	1.48E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	8.10E-03	2.50E-03	0.00E+00	8.10E-03	0.00E+00	0.00E+00	0.00E+00	1.92E-02	1.95E-02	2.41E-03	1.92E-02	0.00E+00	0.00E+00	0.00E+00	3.68E+00	5.93E-03	3.79E+00	1.41E-01	2.34E-01	0.00E+00	1.79E-06	1.85E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	9.73E-03	3.16E-03	0.00E+00	9.73E-03	0.00E+00	0.00E+00	0.00E+00	2.27E-02	2.30E-02	4.38E-03	2.27E-02	0.00E+00	0.00E+00	0.00E+00	4.35E+00	7.12E-03	4.47E+00	1.78E-01	4.25E-01	0.00E+00	2.11E-06	2.22E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	1.14E-02	3.81E-03	0.00E+00	1.14E-02	0.00E+00	0.00E+00	0.00E+00	2.62E-02	2.65E-02	6.34E-03	2.62E-02	0.00E+00	0.00E+00	0.00E+00	5.02E+00	8.31E-03	5.15E+00	2.15E-01	6.15E-01	0.00E+00	2.43E-06	2.60E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	1.30E-02	4.46E-03	0.00E+00	1.30E-02	0.00E+00	0.00E+00	0.00E+00	2.97E-02	3.00E-02	8.30E-03	2.97E-02	0.00E+00	0.00E+00	0.00E+00	5.68E+00	9.50E-03	5.82E+00	2.51E-01	8.06E-01	0.00E+00	2.76E-06	2.97E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	1.46E-02	5.11E-03	0.00E+00	1.46E-02	0.00E+00	0.00E+00	0.00E+00	3.32E-02	3.35E-02	1.03E-02	3.32E-02	0.00E+00	0.00E+00	0.00E+00	6.35E+00	1.07E-02	6.50E+00	2.88E-01	9.96E-01	0.00E+00	3.08E-06	3.34E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	1.79E-02	6.41E-03	0.00E+00	1.79E-02	0.00E+00	0.00E+00	0.00E+00	4.01E-02	4.05E-02	1.42E-02	4.01E-02	0.00E+00	0.00E+00	0.00E+00	7.68E+00	1.31E-02	7.86E+00	3.62E-01	1.38E+00	0.00E+00	3.73E-06	4.09E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	2.11E-02	7.71E-03	0.00E+00	2.11E-02	0.00E+00	0.00E+00	0.00E+00	4.71E-02	4.74E-02	1.81E-02	4.71E-02	0.00E+00	0.00E+00	0.00E+00	9.01E+00	1.55E-02	9.21E+00	4.35E-01	1.76E+00	0.00E+00	4.37E-06	4.83E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	2.44E-02	9.02E-03	0.00E+00	2.44E-02	0.00E+00	4.21E-03	0.00E+00	5.41E-02	5.44E-02	2.20E-02	5.41E-02	0.00E+00	0.00E+00	0.00E+00	1.03E+01	1.78E-02	1.06E+01	5.09E-01	2.14E+00	0.00E+00	5.02E-06	5.58E-08	0.00E+00	0.00E+00	9.69E-01	0.00E+00	0.00E+00	0.00E+00
900	2.76E-02	1.03E-02	0.00E+00	2.76E-02	0.00E+00	9.75E-03	0.00E+00	6.10E-02	6.14E-02	2.60E-02	6.10E-02	0.00E+00	0.00E+00	0.00E+00	1.17E+01	2.02E-02	1.19E+01	5.82E-01	2.52E+00	0.00E+00	5.67E-06	6.32E-08	0.00E+00	0.00E+00	2.24E+00	0.00E+00	0.00E+00	0.00E+00
1,000	3.09E-02	1.16E-02	0.00E+00	3.09E-02	0.00E+00	1.53E-02	0.00E+00	6.80E-02	6.84E-02	2.99E-02	6.80E-02	0.00E+00	0.00E+00	0.00E+00	1.30E+01	2.26E-02	1.33E+01	6.56E-01	2.90E+00	0.00E+00	6.31E-06	7.06E-08	0.00E+00	0.00E+00	3.52E+00	0.00E+00	0.00E+00	0.00E+00
2,000	6.34E-02	2.46E-02	0.00E+00	6.34E-02	0.00E+00	7.07E-02	0.00E+00	1.38E-01	1.38E-01	6.92E-02	1.38E-01	0.00E+00	0.00E+00	3.28E-02	2.63E+01	4.64E-02	2.68E+01	1.39E+00	6.71E+00	0.00E+00	1.28E-05	1.45E-07	0.00E+00	0.00E+00	1.63E+01	6.65E-01	0.00E+00	0.00E+00
3,000	9.59E-02	3.77E-02	0.00E+00	9.59E-02	0.00E+00	1.26E-01	0.00E+00	2.07E-01	2.08E-01	1.08E-01	2.07E-01	8.89E-03	6.83E-02	0.00E+00	3.97E+01	7.02E-02	4.04E+01	2.13E+00	1.05E+01	0.00E+00	1.92E-05	2.20E-07	0.00E+00	0.00E+00	2.90E+01	1.38E+00	0.00E+00	0.00E+00
4,000	1.28E-01	5.07E-02	0.00E+00	1.28E-01	0.00E+00	1.81E-01	0.00E+00	2.77E-01	2.78E-01	1.48E-01	2.77E-01	4.15E-02	1.04E-01	2.36E-03	5.30E+01	9.40E-02	5.39E+01	2.86E+00	1.43E+01	0.00E+00	2.57E-05	2.94E-07	0.00E+00	0.00E+00	4.18E+01	2.10E+00	9.57E-02	4.79E-02
5,000	1.61E-01	6.37E-02	0.00E+00	1.61E-01	0.00E+00	2.37E-01	0.00E+00	3.47E-01	3.48E-01	1.87E-01	3.47E-01	7.40E-02	1.39E-01	1.92E-02	6.63E+01	1.18E-01	6.75E+01	3.60E+00	1.81E+01	0.00E+00	3.22E-05	3.68E-07	0.00E+00	0.00E+00	5.45E+01	2.82E+00	7.78E-01	3.89E-01
6,000	1.93E-01	7.68E-02	0.00E+00	1.93E-01	0.00E+00	2.92E-01	0.00E+00	4.16E-01	4.17E-01	2.26E-01	4.16E-01	1.07E-01	1.75E-01	3.60E-02	7.97E+01	1.42E-01	8.10E+01	4.33E+00	2.20E+01	0.00E+00	3.86E-05	4.43E-07	0.00E+00	0.00E+00	6.73E+01	3.54E+00	1.46E+00	7.31E-01
7,000	2.26E-01	8.98E-02	0.00E+00	2.26E-01	0.00E+00	3.48E-01	0.00E+00	4.86E-01	4.87E-01	2.65E-01	4.86E-01	1.39E-01	2.10E-01	5.29E-02	9.30E+01	1.65E-01	9.45E+01	5.06E+00	2.58E+01	0.00E+00	4.51E-05	5.17E-07	0.00E+00	0.00E+00	8.00E+01	4.26E+00	2.14E+00	1.07E+00
8,000	2.58E-01	1.03E-01	0.00E+00	2.58E-01	0.00E+00	4.03E-01	0.00E+00	5.56E-01	5.57E-01	3.05E-01	5.56E-01	1.72E-01	2.46E-01	6.97E-02	1.06E+02	1.89E-01	1.08E+02	5.80E+00	2.96E+01	0.00E+00	5.16E-05	5.92E-07	0.00E+00	0.00E+00	9.28E+01	4.98E+00	2.83E+00	1.41E+00
9,000	2.91E-01	1.16E-01	0.00E+00	2.91E-01	0.00E+00	4.58E-01	0.00E+00	6.25E-01	6.27E-01	3.44E-01	6.25E-01	2.04E-01	2.81E-01	8.66E-02	1.20E+02	2.13E-01	1.22E+02	6.53E+00	3.34E+01	0.00E+00	5.80E-05	6.66E-07	0.00E+00	0.00E+00	1.06E+02	5.70E+00	3.51E+00	1.75E+00
10,000	3.23E-01	1.29E-01	0.00E+00	3.23E-01	0.00E+00	5.14E-01	0.00E+00	6.95E-01	6.96E-01	3.83E-01	6.95E-01	2.37E-01	3.16E-01	1.03E-01	1.33E+02	2.37E-01	1.35E+02	7.27E+00	3.72E+01	0.00E+00	6.45E-05	7.41E-07	0.00E+00	0.00E+00	1.18E+02	6.41E+00	4.19E+00	2.10E+00

* End of operational period: 16 years

Ogata-Banks Solution, High V High C			Ogata-Banks Solution, Low V Low C		
Post-closure Loading to Dipeta, Scenario 1 (kg/yr)			Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)	Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
3.45E+01	0.0	0.00E+00	4.31E+01	0.0	0.00E+00
2.43E+01	0.0	0.00E+00	3.05E+01	0.0	0.00E+00
1.98E+01	0.0	0.00E+00	2.48E+01	0.0	0.00E+00
1.71E+01	0.0	0.00E+00	2.15E+01	0.0	0.00E+00
1.53E+01	0.0	0.00E+00	1.92E+01	0.0	0.00E+00
1.07E+01	0.0	0.00E+00	1.35E+01	0.0	0.00E+00
8.64E+00	0.0	0.00E+00	1.09E+01	0.0	0.00E+00
7.40E+00	0.0	0.00E+00	9.40E+00	0.0	0.00E+00
6.55E+00	0.0	0.00E+00	8.35E+00	0.0	0.00E+00
5.91E+00	0.0	0.00E+00	7.57E+00	0.0	0.00E+00
5.41E+00	0.0	0.00E+00	6.96E+00	0.0	0.00E+00
5.00E+00	0.0	0.00E+00	6.46E+00	0.0	0.00E+00
4.66E+00	0.0	0.00E+00	6.05E+00	0.0	0.00E+00
4.12E+00	0.0	0.00E+00	5.39E+00	0.0	0.00E+00
3.70E+00	0.0	0.00E+00	4.89E+00	0.0	0.00E+00
3.36E+00	0.0	0.00E+00	4.48E+00	0.0	0.00E+00
3.08E+00	0.0	0.00E+00	4.15E+00	0.0	0.00E+00
2.84E+00	0.0	0.00E+00	3.87E+00	0.0	0.00E+00
1.46E+00	0.0	4.44E+00	2.28E+00	0.0	0.00E+00
7.68E-01	0.3	3.19E+01	1.52E+00	0.0	3.21E-01
2.99E-01	0.7	7.74E+01	1.02E+00	0.1	1.51E+00
-5.83E-02	1.1	1.23E+02	6.52E-01	0.4	3.61E+00
-3.50E-01	1.4	1.59E+02	3.57E-01	0.6	6.22E+00
-5.99E-01	1.6	1.84E+02	1.11E-01	0.9	8.87E+00
-8.17E-01	1.8	2.02E+02	-1.02E-01	1.1	1.13E+01
-1.01E+00	1.8	2.13E+02	-2.90E-01	1.3	1.34E+01
-1.19E+00	1.9	2.19E+02	-4.58E-01	1.5	1.50E+01







DATA SHEET 7 - tin

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	478		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	58	27
	1	34,968	16,319
Ore Stockpile East	0	122	23
	1	87,237	16,284
Ore Stockpile Southwest	0	N/A	271
	1	N/A	29,176
Tailings Facility	0	58	27
	1	34,968	16,319
ROM Ore Stockpiles	0	N/A	3,095
	1	N/A	37,932
Pit to Dipeta	0	758	1,156
	1	21,241	33,161
Pit to Mofia	0	N/A	4,316
	1	N/A	71,701

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	145.109737	21056.83588	57.6504747
	b	61.64	90.23	Scenario 2	99.1288223	9826.523411	26.9035549
	c	-9560	-9560				
Full Contribution	a	0.03	0.06	Scenario 1	3573.83	12,772,235	34,968
	b	-61.64	-90.23	Scenario 2	2441.39	5,960,376	16,319
	c	-152960	-152960				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	211.344446	44,666	122
	b	42.53	98.44	Scenario 2	91.3112368	8,338	23
	c	-9560	-9560				
Full Contribution	a	0.01	0.07	Scenario 1	5644.75	31,863,161	87,237
	b	-42.53	-98.44	Scenario 2	2438.81	5,947,790	16,284
	c	-167300	-167300				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	98.41	Scenario 2	314.412087	98,855	271
	c	-35850	-35850				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-98.41	Scenario 2	3264.45188	10,656,646	29,176
	c	-207930	-207930				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	145.1097	21,057	58
	b	61.64	90.23	Scenario 2	99.12882	9,827	27
	c	-9560	-9560				
Full Contrib	a	0.03	0.06	Scenario 1	3573.826	12,772,235	34,968
	b	-61.64	-90.23	Scenario 2	2441.388	5,960,376	16,319
	c	-152960	-152960				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	127.05	Scenario 2	1063.166	1,130,322	3,095
	c	-191200	-191200				
Full Contrib	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-127.05	Scenario 2	3722.187	13,854,673	37,932
	c	-215100	-215100				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	508.5356	258,608	758
	b	182.74	146.19	Scenario 2	635.6695	404,076	1,156
	c	-119500	-119500				
Full Contrib	a	0.10	0.07	Scenario 1	2782.08	7,739,964	21,241
	b	-182.74	-146.19	Scenario 2	3477.60	12,093,694	33,161
	c	-286800	-286800				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	-140.16	Scenario 2	1248.32	1,558,303	4,316
	c	-239000	-239000				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-182.74	-140.16	Scenario 2	5115.71	26,170,500	71,701
	c	-358500	-358500				

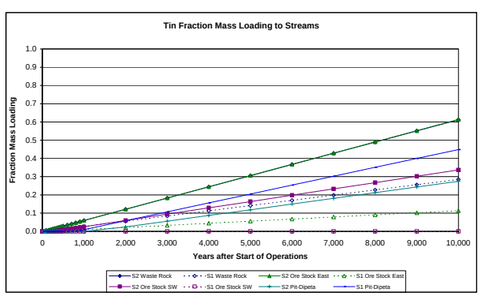
a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

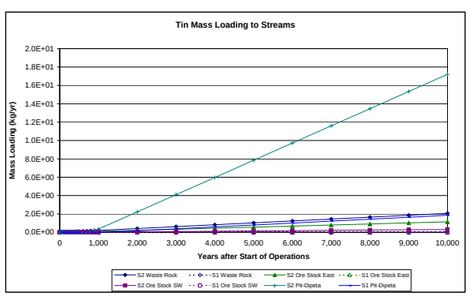
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-04	4.41E-04	0.00E+00	1.90E-04	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.04E-04	1.06E-03	0.00E+00	8.04E-04	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-03	1.67E-03	0.00E+00	1.42E-03	0.00E+00	0.00E+00	0.00E+00
60	6.73E-05	0.00E+00	0.00E+00	6.73E-05	0.00E+00	0.00E+00	0.00E+00	2.03E-03	2.29E-03	0.00E+00	2.03E-03	0.00E+00	0.00E+00	0.00E+00
70	3.54E-04	0.00E+00	0.00E+00	3.54E-04	0.00E+00	0.00E+00	0.00E+00	2.65E-03	2.90E-03	0.00E+00	2.65E-03	0.00E+00	0.00E+00	0.00E+00
80	6.40E-04	0.00E+00	0.00E+00	6.40E-04	0.00E+00	0.00E+00	0.00E+00	3.26E-03	3.52E-03	0.00E+00	3.26E-03	0.00E+00	0.00E+00	0.00E+00
90	9.27E-04	0.00E+00	0.00E+00	9.27E-04	0.00E+00	0.00E+00	0.00E+00	3.87E-03	4.13E-03	0.00E+00	3.87E-03	0.00E+00	0.00E+00	0.00E+00
100	1.21E-03	0.00E+00	0.00E+00	1.21E-03	0.00E+00	0.00E+00	0.00E+00	4.49E-03	4.75E-03	0.00E+00	4.49E-03	0.00E+00	0.00E+00	0.00E+00
150	2.65E-03	3.18E-04	0.00E+00	2.65E-03	0.00E+00	0.00E+00	0.00E+00	7.56E-03	7.82E-03	0.00E+00	7.56E-03	0.00E+00	0.00E+00	0.00E+00
200	4.08E-03	8.92E-04	0.00E+00	4.08E-03	0.00E+00	0.00E+00	0.00E+00	1.06E-02	1.09E-02	0.00E+00	1.06E-02	0.00E+00	0.00E+00	0.00E+00
250	5.51E-03	1.47E-03	0.00E+00	5.51E-03	0.00E+00	0.00E+00	0.00E+00	1.37E-02	1.40E-02	0.00E+00	1.37E-02	0.00E+00	0.00E+00	0.00E+00
300	6.94E-03	2.04E-03	0.00E+00	6.94E-03	0.00E+00	0.00E+00	0.00E+00	1.68E-02	1.70E-02	1.02E-03	1.68E-02	0.00E+00	0.00E+00	0.00E+00
350	8.37E-03	2.61E-03	0.00E+00	8.37E-03	0.00E+00	0.00E+00	0.00E+00	1.98E-02	2.01E-02	2.75E-03	1.98E-02	0.00E+00	0.00E+00	0.00E+00
400	9.81E-03	3.19E-03	0.00E+00	9.81E-03	0.00E+00	0.00E+00	0.00E+00	2.29E-02	2.32E-02	4.47E-03	2.29E-02	0.00E+00	0.00E+00	0.00E+00
450	1.12E-02	3.76E-03	0.00E+00	1.12E-02	0.00E+00	0.00E+00	0.00E+00	2.60E-02	2.63E-02	6.20E-03	2.60E-02	0.00E+00	0.00E+00	0.00E+00
500	1.27E-02	4.34E-03	0.00E+00	1.27E-02	0.00E+00	0.00E+00	0.00E+00	2.90E-02	2.93E-02	7.93E-03	2.90E-02	0.00E+00	0.00E+00	0.00E+00
600	1.55E-02	5.48E-03	0.00E+00	1.55E-02	0.00E+00	0.00E+00	0.00E+00	3.52E-02	3.55E-02	1.14E-02	3.52E-02	0.00E+00	0.00E+00	0.00E+00
700	1.84E-02	6.63E-03	0.00E+00	1.84E-02	0.00E+00	0.00E+00	0.00E+00	4.13E-02	4.16E-02	1.49E-02	4.13E-02	0.00E+00	0.00E+00	0.00E+00
800	2.13E-02	7.78E-03	0.00E+00	2.13E-02	0.00E+00	0.00E+00	0.00E+00	4.75E-02	4.78E-02	1.83E-02	4.75E-02	0.00E+00	0.00E+00	0.00E+00
900	2.41E-02	8.93E-03	0.00E+00	2.41E-02	0.00E+00	4.49E-03	0.00E+00	5.36E-02	5.39E-02	2.18E-02	5.36E-02	0.00E+00	0.00E+00	0.00E+00
1,000	2.70E-02	1.01E-02	0.00E+00	2.70E-02	0.00E+00	9.37E-03	0.00E+00	5.97E-02	6.01E-02	2.52E-02	5.97E-02	0.00E+00	0.00E+00	0.00E+00
2,000	5.56E-02	2.16E-02	0.00E+00	5.56E-02	0.00E+00	5.82E-02	0.00E+00	1.21E-01	1.22E-01	5.98E-02	1.21E-01	0.00E+00	2.48E-02	0.00E+00
3,000	8.43E-02	3.30E-02	0.00E+00	8.43E-02	0.00E+00	1.07E-01	0.00E+00	1.82E-01	1.83E-01	9.44E-02	1.82E-01	0.00E+00	5.60E-02	0.00E+00
4,000	1.13E-01	4.45E-02	0.00E+00	1.13E-01	0.00E+00	1.56E-01	0.00E+00	2.44E-01	2.45E-01	1.29E-01	2.44E-01	2.60E-02	8.73E-02	0.00E+00
5,000	1.42E-01	5.60E-02	0.00E+00	1.42E-01	0.00E+00	2.05E-01	0.00E+00	3.05E-01	3.06E-01	1.64E-01	3.05E-01	5.47E-02	1.19E-01	9.40E-03
6,000	1.70E-01	6.75E-02	0.00E+00	1.70E-01	0.00E+00	2.53E-01	0.00E+00	3.67E-01	3.68E-01	1.98E-01	3.67E-01	8.34E-02	1.50E-01	2.42E-02
7,000	1.99E-01	7.90E-02	0.00E+00	1.99E-01	0.00E+00	3.02E-01	0.00E+00	4.28E-01	4.29E-01	2.33E-01	4.28E-01	1.12E-01	1.81E-01	3.91E-02
8,000	2.28E-01	9.04E-02	0.00E+00	2.28E-01	0.00E+00	3.51E-01	0.00E+00	4.89E-01	4.91E-01	2.67E-01	4.89E-01	1.41E-01	2.12E-01	5.39E-02
9,000	2.56E-01	1.02E-01	0.00E+00	2.56E-01	0.00E+00	4.00E-01	0.00E+00	5.51E-01	5.52E-01	3.02E-01	5.51E-01	1.70E-01	2.44E-01	6.88E-02
10,000	2.85E-01	1.13E-01	0.00E+00	2.85E-01	0.00E+00	4.49E-01	0.00E+00	6.12E-01	6.14E-01	3.37E-01	6.12E-01	1.98E-01	2.75E-01	8.36E-02

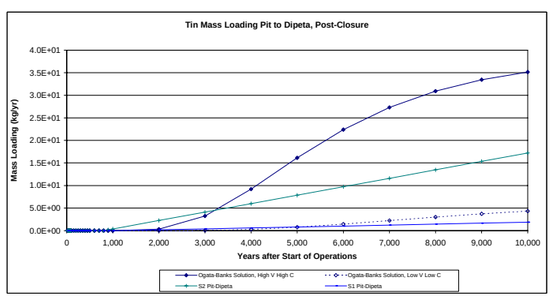
Time from Start of Operations (Years)*	Loading Calculations to Kasana (kg/year): Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	6.42E-04	0.00E+00	8.18E-04	0.00E+00	0.00E+00	0.00E+00	6.63E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	2.71E-03	0.00E+00	1.96E-03	0.00E+00	0.00E+00	0.00E+00	2.80E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	4.79E-03	0.00E+00	3.10E-03	0.00E+00	0.00E+00	0.00E+00	4.94E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	6.86E-03	2.22E-05	4.24E-03	0.00E+00	0.00E+00	0.00E+00	7.08E-10	1.35E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	8.93E-03	1.17E-04	5.38E-03	0.00E+00	0.00E+00	0.00E+00	9.23E-10	7.08E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	1.10E-02	2.11E-04	6.52E-03	0.00E+00	0.00E+00	0.00E+00	1.14E-09	1.28E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	1.31E-02	3.06E-04	7.66E-03	0.00E+00	0.00E+00	0.00E+00	1.35E-09	1.85E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	1.51E-02	4.00E-04	8.80E-03	0.00E+00	0.00E+00	0.00E+00	1.56E-09	2.43E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	2.55E-02	8.73E-04	1.45E-02	5.94E-05	0.00E+00	0.00E+00	2.64E-09	5.29E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	3.59E-02	1.35E-03	2.02E-02	1.67E-04	0.00E+00	0.00E+00	8.16E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	4.62E-02	1.82E-03	2.59E-02	2.74E-04	0.00E+00	0.00E+00	4.78E-09	1.10E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	5.66E-02	2.29E-03	3.16E-02	3.81E-04	9.41E-04	0.00E+00	5.85E-09	1.39E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	6.70E-02	2.76E-03	3.73E-02	4.88E-04	2.54E-03	0.00E+00	6.92E-09	1.68E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	7.73E-02	3.24E-03	4.30E-02	5.95E-04	4.15E-03	0.00E+00	7.99E-09	1.96E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	8.77E-02	3.71E-03	4.87E-02	7.03E-04	5.75E-03	0.00E+00	9.06E-09	2.25E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	9.80E-02	4.18E-03	5.44E-02	8.10E-04	7.35E-03	0.00E+00	1.01E-08	2.54E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	1.19E-01	5.12E-03	6.58E-02	1.02E-03	1.06E-02	0.00E+00	1.23E-08	3.11E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	1.39E-01	6.07E-03	7.72E-02	1.24E-03	1.38E-02	0.00E+00	1.44E-08	3.68E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	1.60E-01	7.02E-03	8.86E-02	1.45E-03	1.70E-02	0.00E+00	1.65E-08	4.26E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	1.81E-01	7.96E-03	1.00E-01	1.67E-03	2.02E-02	0.00E+00	1.87E-08	4.83E-09	0.00E+00	0.00E+00	1.72E-01	0.00E+00	0.00E+00	0.00E+00
1,000	2.02E-01	8.91E-03	1.11E-01	1.88E-03	2.34E-02	0.00E+00	2.08E-08	5.40E-09	0.00E+00	0.00E+00	3.59E-01	0.00E+00	0.00E+00	0.00E+00
2,000	4.09E-01	1.84E-02	2.25E-01	4.03E-03	5.54E-02	0.00E+00	4.22E-08	1.11E-08	0.00E+00	0.00E+00	2.23E+00	1.68E-01	0.00E+00	0.00E+00
3,000	6.16E-01	2.78E-02	3.39E-01	6.17E-03	8.75E-02	0.00E+00	6.36E-08	1.69E-08	0.00E+00	0.00E+00	4.10E+00	3.79E-01	0.00E+00	0.00E+00
4,000	8.23E-01	3.73E-02	4.53E-01	8.32E-03	1.20E-01	0.00E+00	8.50E-08	2.26E-08	0.00E+00	0.00E+00	5.98E+00	5.90E-01	0.00E+00	0.00E+00
5,000	1.03E+00	4.67E-02	5.67E-01	1.05E-02	1.52E-01	0.00E+00	1.06E-07	2.83E-08	0.00E+00	0.00E+00	7.85E+00	8.01E-01	6.35E-02	6.35E-02
6,000	1.24E+00	5.62E-02	6.81E-01	1.26E-02	1.84E-01	0.00E+00	1.28E-07	3.41E-08	0.00E+00	0.00E+00	9.72E+00	1.01E+00	1.64E-01	1.64E-01
7,000	1.45E+00	6.56E-02	7.95E-01	1.47E-02	2.16E-01	0.00E+00	1.49E-07	3.98E-08	0.00E+00	0.00E+00	1.16E+01	1.22E+00	2.64E-01	2.64E-01
8,000	1.65E+00	7.51E-02	9.09E-01	1.69E-02	2.48E-01	0.00E+00	1.71E-07	4.55E-08	0.00E+00	0.00E+00	1.35E+01	1.43E+00	3.64E-01	3.64E-01
9,000	1.86E+00	8.45E-02	1.02E+00	1.90E-02	2.80E-01	0.00E+00	1.92E-07	5.13E-08	0.00E+00	0.00E+00	1.53E+01	1.65E+00	4.65E-01	4.65E-01
10,000	2.07E+00	9.40E-02	1.14E+00	2.12E-02	3.12E-01	0.00E+00	2.13E-07	5.70E-08	0.00E+00	0.00E+00	1.72E+01	1.86E+00	5.65E-01	5.65E-01

* End of operational period: 16 years

Ogata-Banks Solution, High V High C — Post-closure Loading to Dipeta, Scenario 1 (kg/yr)			Ogata-Banks Solution, Low V Low C — Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)	Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
3.67E+01	0.0	0.00E+00	4.59E+01	0.0	0.00E+00
2.59E+01	0.0	0.00E+00	3.25E+01	0.0	0.00E+00
2.11E+01	0.0	0.00E+00	2.65E+01	0.0	0.00E+00
1.83E+01	0.0	0.00E+00	2.29E+01	0.0	0.00E+00
1.63E+01	0.0	0.00E+00	2.05E+01	0.0	0.00E+00
1.14E+01	0.0	0.00E+00	1.44E+01	0.0	0.00E+00
9.24E+00	0.0	0.00E+00	1.17E+01	0.0	0.00E+00
7.93E+00	0.0	0.00E+00	1.00E+01	0.0	0.00E+00
7.02E+00	0.0	0.00E+00	8.93E+00	0.0	0.00E+00
6.35E+00	0.0	0.00E+00	8.10E+00	0.0	0.00E+00
5.82E+00	0.0	0.00E+00	7.45E+00	0.0	0.00E+00
5.39E+00	0.0	0.00E+00	6.93E+00	0.0	0.00E+00
5.03E+00	0.0	0.00E+00	6.49E+00	0.0	0.00E+00
4.46E+00	0.0	0.00E+00	5.80E+00	0.0	0.00E+00
4.02E+00	0.0	0.00E+00	5.27E+00	0.0	0.00E+00
3.66E+00	0.0	0.00E+00	4.84E+00	0.0	0.00E+00
3.36E+00	0.0	0.00E+00	4.49E+00	0.0	0.00E+00
3.11E+00	0.0	0.00E+00	4.19E+00	0.0	0.00E+00
1.69E+00	0.0	3.28E-01	2.53E+00	0.0	0.00E+00
9.75E-01	0.2	3.22E+00	1.74E+00	0.0	4.61E-02
5.01E-01	0.5	9.18E+00	1.23E+00	0.1	2.74E-01
1.42E-01	0.8	1.61E+01	8.58E-01	0.2	7.61E-01
-1.49E-01	1.2	2.24E+01	5.59E-01	0.4	1.45E+00
-3.96E-01	1.4	2.73E+01	3.11E-01	0.7	2.23E+00
-6.12E-01	1.6	3.09E+01	9.81E-02	0.9	3.01E+00
-8.04E-01	1.7	3.34E+01	-8.93E-02	1.1	3.72E+00
-9.78E-01	1.8	3.52E+01	-2.57E-01	1.3	4.34E+00







DATA SHEET 8 - selenium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	712		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	86	40
	1	52,067	24,298
Ore Stockpile East	0	182	34
	1	129,893	24,247
Ore Stockpile Southwest	0	N/A	403
	1	N/A	43,443
Tailings Facility	0	86	40
	1	52,067	24,298
ROM Ore Stockpiles	0	N/A	4,608
	1	N/A	56,480
Pit to Dipeta	0	1,104	1,697
	1	31,603	49,351
Pit to Mofia	0	N/A	6,403
	1	N/A	106,736

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	177.068066	31353.1	85.8401095
	b	75.22	110.10	Scenario 2	120.960517	14631.44667	40.0587178
	c	-14234.6	-14234.6				
Full Contribution	a	0.03	0.06	Scenario 1	4360.91	19,017,538	52,067
	b	-75.22	-110.10	Scenario 2	2979.07	8,874,851	24,298
	c	-227753.6	-227753.6				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	257.890015	66,507	182
	b	51.90	120.12	Scenario 2	111.421221	12,415	34
	c	-14234.6	-14234.6				
Full Contribution	a	0.01	0.07	Scenario 1	6887.92	47,443,447	129,893
	b	-51.90	-120.12	Scenario 2	2975.92	8,856,110	24,247
	c	-249105.5	-249105.5				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	120.08	Scenario 2	383.656819	147,193	403
	c	-53379.75	-53379.75				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-120.08	Scenario 2	3983.40036	15,867,478	43,443
	c	-309602.55	-309602.55				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	177.0681	31,353	86
	b	75.22	110.10	Scenario 2	120.9605	14,631	40
	c	-14234.6	-14234.6				
Full Contribu	a	0.03	0.06	Scenario 1	4360.91	19,017,538	52,067
	b	-75.22	-110.10	Scenario 2	2979.069	8,874,851	24,298
	c	-227753.6	-227753.6				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	155.03	Scenario 2	1297.313	1,683,021	4,608
	c	-284692	-284692				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-155.03	Scenario 2	4541.945	20,629,260	56,480
	c	-320278.5	-320278.5				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	620.5332	385,061	1,104
	b	222.99	178.39	Scenario 2	775.6665	601,659	1,697
	c	-177932.5	-177932.5				
Full Contribu	a	0.10	0.07	Scenario 1	3394.79	11,524,612	31,603
	b	-222.99	-178.39	Scenario 2	4243.49	18,007,207	49,351
	c	-427038	-427038				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	171.02	Scenario 2	1523.245	2,320,274	6,403
	c	-355865	-355865				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-222.99	-171.02	Scenario 2	6242.37	38,967,218	106,736
	c	-533797.5	-533797.5				

Scenario 1

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	8.00E-05	0.00E+00	0.00E+00	8.00E-05	0.00E+00	0.00E+00	0.00E+00
100	2.72E-04	0.00E+00	0.00E+00	2.72E-04	0.00E+00	0.00E+00	0.00E+00
150	1.23E-03	0.00E+00	0.00E+00	1.23E-03	0.00E+00	0.00E+00	0.00E+00
200	2.20E-03	1.38E-04	0.00E+00	2.20E-03	0.00E+00	0.00E+00	0.00E+00
250	3.16E-03	5.24E-04	0.00E+00	3.16E-03	0.00E+00	0.00E+00	0.00E+00
300	4.12E-03	9.09E-04	0.00E+00	4.12E-03	0.00E+00	0.00E+00	0.00E+00
350	5.08E-03	1.29E-03	0.00E+00	5.08E-03	0.00E+00	0.00E+00	0.00E+00
400	6.04E-03	1.68E-03	0.00E+00	6.04E-03	0.00E+00	0.00E+00	0.00E+00
450	7.01E-03	2.07E-03	0.00E+00	7.01E-03	0.00E+00	0.00E+00	0.00E+00
500	7.97E-03	2.45E-03	0.00E+00	7.97E-03	0.00E+00	0.00E+00	0.00E+00
600	9.89E-03	3.22E-03	0.00E+00	9.89E-03	0.00E+00	0.00E+00	0.00E+00
700	1.18E-02	3.99E-03	0.00E+00	1.18E-02	0.00E+00	0.00E+00	0.00E+00
800	1.37E-02	4.76E-03	0.00E+00	1.37E-02	0.00E+00	0.00E+00	0.00E+00
900	1.57E-02	5.53E-03	0.00E+00	1.57E-02	0.00E+00	0.00E+00	0.00E+00
1,000	1.76E-02	6.31E-03	0.00E+00	1.76E-02	0.00E+00	0.00E+00	0.00E+00
2,000	3.68E-02	1.40E-02	0.00E+00	3.68E-02	0.00E+00	2.77E-02	0.00E+00
3,000	5.61E-02	2.17E-02	0.00E+00	5.61E-02	0.00E+00	6.05E-02	0.00E+00
4,000	7.53E-02	2.94E-02	0.00E+00	7.53E-02	0.00E+00	9.33E-02	0.00E+00
5,000	9.45E-02	3.71E-02	0.00E+00	9.45E-02	0.00E+00	1.26E-01	0.00E+00
6,000	1.14E-01	4.49E-02	0.00E+00	1.14E-01	0.00E+00	1.59E-01	0.00E+00
7,000	1.33E-01	5.26E-02	0.00E+00	1.33E-01	0.00E+00	1.92E-01	0.00E+00
8,000	1.52E-01	6.03E-02	0.00E+00	1.52E-01	0.00E+00	2.24E-01	0.00E+00
9,000	1.71E-01	6.80E-02	0.00E+00	1.71E-01	0.00E+00	2.57E-01	0.00E+00
10,000	1.91E-01	7.57E-02	0.00E+00	1.91E-01	0.00E+00	2.90E-01	0.00E+00

Scenario 2

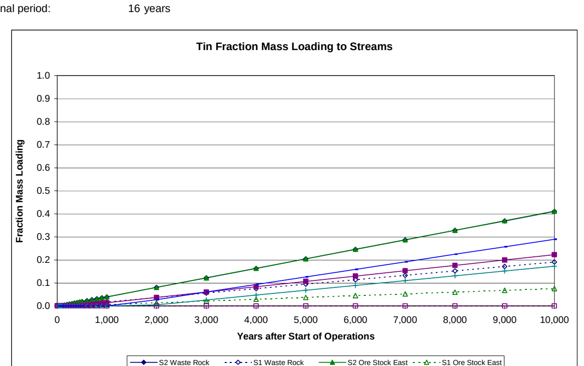
Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	2.48E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	4.10E-04	6.61E-04	0.00E+00	4.10E-04	0.00E+00	0.00E+00	0.00E+00
60	8.22E-04	1.07E-03	0.00E+00	8.22E-04	0.00E+00	0.00E+00	0.00E+00
70	1.23E-03	1.49E-03	0.00E+00	1.23E-03	0.00E+00	0.00E+00	0.00E+00
80	1.65E-03	1.90E-03	0.00E+00	1.65E-03	0.00E+00	0.00E+00	0.00E+00
90	2.06E-03	2.31E-03	0.00E+00	2.06E-03	0.00E+00	0.00E+00	0.00E+00
100	2.47E-03	2.73E-03	0.00E+00	2.47E-03	0.00E+00	0.00E+00	0.00E+00
150	4.53E-03	4.79E-03	0.00E+00	4.53E-03	0.00E+00	0.00E+00	0.00E+00
200	6.59E-03	6.86E-03	0.00E+00	6.59E-03	0.00E+00	0.00E+00	0.00E+00
250	8.65E-03	8.92E-03	0.00E+00	8.65E-03	0.00E+00	0.00E+00	0.00E+00
300	1.07E-02	1.10E-02	0.00E+00	1.07E-02	0.00E+00	0.00E+00	0.00E+00
350	1.28E-02	1.31E-02	0.00E+00	1.28E-02	0.00E+00	0.00E+00	0.00E+00
400	1.48E-02	1.51E-02	0.00E+00	1.48E-02	0.00E+00	0.00E+00	0.00E+00
450	1.69E-02	1.72E-02	1.09E-03	1.69E-02	0.00E+00	0.00E+00	0.00E+00
500	1.90E-02	1.92E-02	2.25E-03	1.90E-02	0.00E+00	0.00E+00	0.00E+00
600	2.31E-02	2.34E-02	4.58E-03	2.31E-02	0.00E+00	0.00E+00	0.00E+00
700	2.72E-02	2.75E-02	6.90E-03	2.72E-02	0.00E+00	0.00E+00	0.00E+00
800	3.13E-02	3.16E-02	9.22E-03	3.13E-02	0.00E+00	0.00E+00	0.00E+00
900	3.54E-02	3.58E-02	1.15E-02	3.54E-02	0.00E+00	0.00E+00	0.00E+00
1,000	3.96E-02	3.99E-02	1.39E-02	3.96E-02	0.00E+00	0.00E+00	0.00E+00
2,000	8.08E-02	8.12E-02	3.71E-02	8.08E-02	0.00E+00	5.30E-03	0.00E+00
3,000	1.22E-01	1.22E-01	6.03E-02	1.22E-01	0.00E+00	2.63E-02	0.00E+00
4,000	1.63E-01	1.64E-01	8.36E-02	1.63E-01	0.00E+00	4.73E-02	0.00E+00
5,000	2.04E-01	2.05E-01	1.07E-01	2.04E-01	7.56E-03	6.83E-02	0.00E+00
6,000	2.46E-01	2.46E-01	1.30E-01	2.46E-01	2.68E-02	8.92E-02	0.00E+00
7,000	2.87E-01	2.88E-01	1.53E-01	2.87E-01	4.61E-02	1.10E-01	5.46E-03
8,000	3.28E-01	3.29E-01	1.77E-01	3.28E-01	6.54E-02	1.31E-01	1.54E-02
9,000	3.69E-01	3.70E-01	2.00E-01	3.69E-01	8.47E-02	1.52E-01	2.54E-02
10,000	4.11E-01	4.12E-01	2.23E-01	4.11E-01	1.04E-01	1.73E-01	3.54E-02

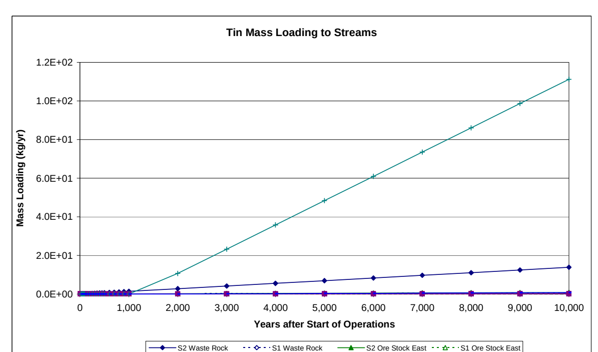
Loading Calculations to Kasana (kg/year)

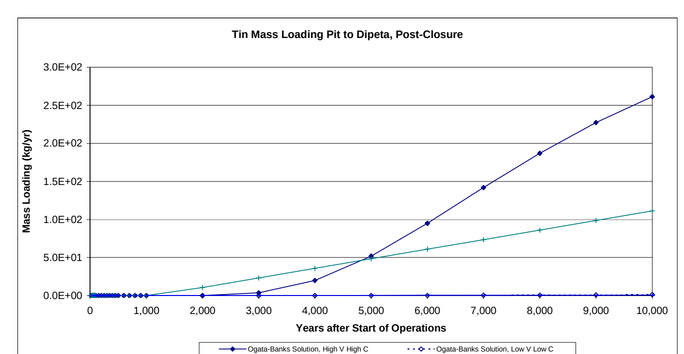
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	4.49E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	1.38E-02	0.00E+00	1.20E-03	0.00E+00	0.00E+00	0.00E+00	1.60E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	2.77E-02	0.00E+00	1.94E-03	0.00E+00	0.00E+00	0.00E+00	3.21E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	4.16E-02	0.00E+00	2.69E-03	0.00E+00	0.00E+00	0.00E+00	4.82E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	5.55E-02	0.00E+00	3.43E-03	0.00E+00	0.00E+00	0.00E+00	6.43E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	6.94E-02	2.70E-04	4.18E-03	0.00E+00	0.00E+00	0.00E+00	8.04E-08	1.48E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	8.33E-02	9.18E-04	4.93E-03	0.00E+00	0.00E+00	0.00E+00	9.64E-08	5.04E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	1.53E-01	4.16E-03	8.66E-03	0.00E+00	0.00E+00	0.00E+00	1.77E-07	2.28E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	2.22E-01	7.40E-03	1.24E-02	2.52E-05	0.00E+00	0.00E+00	2.57E-07	4.06E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	2.92E-01	1.06E-02	1.61E-02	9.54E-05	0.00E+00	0.00E+00	3.38E-07	5.84E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	3.61E-01	1.39E-02	1.99E-02	1.66E-04	0.00E+00	0.00E+00	4.18E-07	7.62E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	4.31E-01	1.71E-02	2.36E-02	2.36E-04	0.00E+00	0.00E+00	4.99E-07	9.39E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	5.00E-01	2.04E-02	2.73E-02	3.06E-04	0.00E+00	0.00E+00	5.79E-07	1.12E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	5.70E-01	2.36E-02	3.11E-02	3.76E-04	9.87E-04	0.00E+00	6.60E-07	1.29E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	6.39E-01	2.69E-02	3.48E-02	4.46E-04	2.04E-03	0.00E+00	7.40E-07	1.47E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	7.78E-01	3.33E-02	4.22E-02	5.87E-04	4.14E-03	0.00E+00	9.01E-07	1.83E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	9.17E-01	3.98E-02	4.97E-02	7.27E-04	6.24E-03	0.00E+00	1.06E-06	2.18E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	1.06E+00	4.63E-02	5.72E-02	8.68E-04	8.34E-03	0.00E+00	1.22E-06	2.54E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	1.19E+00	5.28E-02	6.46E-02	1.01E-03	1.04E-02	0.00E+00	1.38E-06	2.90E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	1.33E+00	5.93E-02	7.21E-02	1.15E-03	1.25E-02	0.00E+00	1.54E-06	3.25E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	2.72E+00	1.24E-01	1.47E-01	2.55E-03	3.35E-02	0.00E+00	3.15E-06	6.81E-08	0.00E+00	0.00E+00	1.06E+01	2.15E-02	0.00E+00	0.00E+00
3,000	4.11E+00	1.89E-01	2.21E-01	3.96E-03	5.45E-02	0.00E+00	4.76E-06	1.04E-07	0.00E+00	0.00E+00	2.32E+01	1.07E-01	0.00E+00	0.00E+00
4,000	5.50E+00	2.54E-01	2.96E-01	5.36E-03	7.55E-02	0.00E+00	6.37E-06	1.39E-07	0.00E+00	0.00E+00	3.58E+01	1.92E-01	0.00E+00	0.00E+00
5,000	6.89E+00	3.19E-01	3.71E-01	6.76E-03	9.65E-02	0.00E+00	7.98E-06	1.75E-07	0.00E+00	0.00E+00	4.84E+01	2.77E-01	0.00E+00	0.00E+00
6,000	8.28E+00	3.83E-01	4.45E-01	8.17E-03	1.18E-01	0.00E+00	9.59E-06	2.10E-07	0.00E+00	0.00E+00	6.09E+01	3.62E-01	0.00E+00	0.00E+00
7,000	9.67E+00	4.48E-01	5.20E-01	9.57E-03	1.39E-01	0.00E+00	1.12E-05	2.46E-07	0.00E+00	0.00E+00	7.35E+01	4.47E-01	3.69E-01	2.21E-02
8,000	1.11E+01	5.13E-01	5.95E-01	1.10E-02	1.60E-01	0.00E+00	1.28E-05	2.81E-07	0.00E+00	0.00E+00	8.61E+01	5.32E-01	1.04E+00	6.25E-02
9,000	1.24E+01	5.78E-01	6.69E-01	1.24E-02	1.80E-01	0.00E+00	1.44E-05	3.17E-07	0.00E+00	0.00E+00	9.87E+01	6.17E-01	1.72E+00	1.03E-01
10,000	1.38E+01	6.43E-01	7.44E-01	1.38E-02	2.01E-01	0.00E+00	1.60E-05	3.53E-07	0.00E+00	0.00E+00	1.11E+02	7.02E-01	2.39E+00	1.43E-01

Time from Start of Operations (Years)*	Ogata-Banks Solution, High V High C — Post-closure Loading to Dipeta, Scenario 1 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)	Ogata-Banks Solution, Low V Low C — Post-closure Loading to Dipeta, Scenario 2 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)
0						
10						
16						
20	N/A	N/A	0	N/A	N/A	0
30	N/A	N/A	0	N/A	N/A	0
40	N/A	N/A	0	N/A	N/A	0
50	N/A	N/A	0	N/A	N/A	0
60	4.49E+01	0.0	0.00E+00	5.61E+01	0.0	0.00E+00
70	3.17E+01	0.0	0.00E+00	3.96E+01	0.0	0.00E+00
80	2.58E+01	0.0	0.00E+00	3.23E+01	0.0	0.00E+00
90	2.23E+01	0.0	0.00E+00	2.80E+01	0.0	0.00E+00
100	2.00E+01	0.0	0.00E+00	2.50E+01	0.0	0.00E+00
150	1.40E+01	0.0	0.00E+00	1.76E+01	0.0	0.00E+00
200	1.14E+01	0.0	0.00E+00	1.43E+01	0.0	0.00E+00
250	9.79E+00	0.0	0.00E+00	1.24E+01	0.0	0.00E+00
300	8.70E+00	0.0	0.00E+00	1.10E+01	0.0	0.00E+00
350	7.89E+00	0.0	0.00E+00	1.00E+01	0.0	0.00E+00
400	7.26E+00	0.0	0.00E+00	9.22E+00	0.0	0.00E+00
450	6.75E+00	0.0	0.00E+00	8.59E+00	0.0	0.00E+00
500	6.32E+00	0.0	0.00E+00	8.07E+00	0.0	0.00E+00
600	5.64E+00	0.0	0.00E+00	7.24E+00	0.0	0.00E+00
700	5.12E+00	0.0	0.00E+00	6.60E+00	0.0	0.00E+00
800	4.70E+00	0.0	0.00E+00	6.10E+00	0.0	0.00E+00
900	4.36E+00	0.0	0.00E+00	5.68E+00	0.0	0.00E+00
1,000	4.06E+00	0.0	0.00E+00	5.32E+00	0.0	0.00E+00
2,000	2.44E+00	0.0	0.00E+00	3.40E+00	0.0	0.00E+00
3,000	1.66E+00	0.0	3.66E+00	2.50E+00	0.0	0.00E+00
4,000	1.15E+00	0.1	1.98E+01	1.94E+00	0.0	1.24E-02
5,000	7.79E-01	0.3	5.19E+01	1.53E+00	0.0	6.15E-02
6,000	4.82E-01	0.5	9.50E+01	1.21E+00	0.1	1.74E-01
7,000	2.35E-01	0.7	1.42E+02	9.54E-01	0.2	3.59E-01
8,000	2.19E-02	1.0	1.87E+02	7.34E-01	0.3	6.06E-01
9,000	-1.66E-01	1.2	2.27E+02	5.43E-01	0.4	8.97E-01
10,000	-3.34E-01	1.4	2.61E+02	3.74E-01	0.6	1.21E+00

* End of operational period: 16 years







DATA SHEET 9 - iron

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	717		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	86	40
	1	52,416	24,461
Ore Stockpile East	0	183	34
	1	130,764	24,409
Ore Stockpile Southwest	0	N/A	406
	1	N/A	43,734
Tailings Facility	0	86	40
	1	52,416	24,461
ROM Ore Stockpiles	0	N/A	4,639
	1	N/A	56,858
Pit to Dipeta	0	1,111	1,708
	1	31,814	49,681
Pit to Mofia	0	N/A	6,445
	1	N/A	107,451

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	177.660428	31563.22784	86.4154082
	b	75.47	110.47	Scenario 2	121.365178	14729.50633	40.3271905
	c	-14330	-14330				
Full Contribution	a	0.03	0.06	Scenario 1	4375.50	19,144,993	52,416
	b	-75.47	-110.47	Scenario 2	2989.03	8,934,330	24,461
	c	-229280	-229280				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	258.752758	66,953	183
	b	52.07	120.53	Scenario 2	111.793969	12,498	34
	c	-14330	-14330				
Full Contribution	a	0.01	0.07	Scenario 1	6910.96	47,761,412	130,764
	b	-52.07	-120.53	Scenario 2	2985.88	8,915,464	24,409
	c	-250775	-250775				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	120.48	Scenario 2	384.940302	148,179	406
	c	-53737.5	-53737.5				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-120.48	Scenario 2	3996.72641	15,973,822	43,734
	c	-311677.5	-311677.5				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	177.6604	31,563	86
	b	75.47	110.47	Scenario 2	121.3652	14,730	40
	c	-14330	-14330				
Full Contribu	a	0.03	0.06	Scenario 1	4375.499	19,144,993	52,416
	b	-75.47	-110.47	Scenario 2	2989.035	8,934,330	24,461
	c	-229280	-229280				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	155.54	Scenario 2	1301.653	1,694,301	4,639
	c	-286600	-286600				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-155.54	Scenario 2	4557.139	20,767,517	56,858
	c	-322425	-322425				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	622.6091	387,642	1,111
	b	223.73	178.99	Scenario 2	778.2614	605,691	1,708
	c	-179125	-179125				
Full Contribu	a	0.10	0.07	Scenario 1	3406.15	11,601,850	31,814
	b	-223.73	-178.99	Scenario 2	4257.69	18,127,891	49,681
	c	-429900	-429900				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	171.60	Scenario 2	1528.341	2,335,825	6,445
	c	-358250	-358250				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-223.73	-171.60	Scenario 2	6263.26	39,228,375	107,451
	c	-537375	-537375				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.37E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.96E-04	6.47E-04	0.00E+00	3.96E-04	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.06E-04	1.06E-03	0.00E+00	8.06E-04	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.22E-03	1.47E-03	0.00E+00	1.22E-03	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-03	1.88E-03	0.00E+00	1.62E-03	0.00E+00	0.00E+00	0.00E+00
90	6.85E-05	0.00E+00	0.00E+00	6.85E-05	0.00E+00	0.00E+00	0.00E+00	2.03E-03	2.29E-03	0.00E+00	2.03E-03	0.00E+00	0.00E+00	0.00E+00
100	2.60E-04	0.00E+00	0.00E+00	2.60E-04	0.00E+00	0.00E+00	0.00E+00	2.44E-03	2.70E-03	0.00E+00	2.44E-03	0.00E+00	0.00E+00	0.00E+00
150	1.22E-03	0.00E+00	0.00E+00	1.22E-03	0.00E+00	0.00E+00	0.00E+00	4.49E-03	4.75E-03	0.00E+00	4.49E-03	0.00E+00	0.00E+00	0.00E+00
200	2.17E-03	1.28E-04	0.00E+00	2.17E-03	0.00E+00	0.00E+00	0.00E+00	6.54E-03	6.80E-03	0.00E+00	6.54E-03	0.00E+00	0.00E+00	0.00E+00
250	3.13E-03	5.11E-04	0.00E+00	3.13E-03	0.00E+00	0.00E+00	0.00E+00	8.59E-03	8.85E-03	0.00E+00	8.59E-03	0.00E+00	0.00E+00	0.00E+00
300	4.08E-03	8.94E-04	0.00E+00	4.08E-03	0.00E+00	0.00E+00	0.00E+00	1.06E-02	1.09E-02	0.00E+00	1.06E-02	0.00E+00	0.00E+00	0.00E+00
350	5.04E-03	1.28E-03	0.00E+00	5.04E-03	0.00E+00	0.00E+00	0.00E+00	1.27E-02	1.30E-02	0.00E+00	1.27E-02	0.00E+00	0.00E+00	0.00E+00
400	5.99E-03	1.66E-03	0.00E+00	5.99E-03	0.00E+00	0.00E+00	0.00E+00	1.47E-02	1.50E-02	0.00E+00	1.47E-02	0.00E+00	0.00E+00	0.00E+00
450	6.95E-03	2.04E-03	0.00E+00	6.95E-03	0.00E+00	0.00E+00	0.00E+00	1.68E-02	1.71E-02	1.02E-03	1.68E-02	0.00E+00	0.00E+00	0.00E+00
500	7.90E-03	2.43E-03	0.00E+00	7.90E-03	0.00E+00	0.00E+00	0.00E+00	1.88E-02	1.91E-02	2.18E-03	1.88E-02	0.00E+00	0.00E+00	0.00E+00
600	9.81E-03	3.19E-03	0.00E+00	9.81E-03	0.00E+00	0.00E+00	0.00E+00	2.29E-02	2.32E-02	4.48E-03	2.29E-02	0.00E+00	0.00E+00	0.00E+00
700	1.17E-02	3.96E-03	0.00E+00	1.17E-02	0.00E+00	0.00E+00	0.00E+00	2.70E-02	2.73E-02	6.79E-03	2.70E-02	0.00E+00	0.00E+00	0.00E+00
800	1.36E-02	4.72E-03	0.00E+00	1.36E-02	0.00E+00	0.00E+00	0.00E+00	3.11E-02	3.14E-02	9.10E-03	3.11E-02	0.00E+00	0.00E+00	0.00E+00
900	1.55E-02	5.49E-03	0.00E+00	1.55E-02	0.00E+00	0.00E+00	0.00E+00	3.52E-02	3.55E-02	1.14E-02	3.52E-02	0.00E+00	0.00E+00	0.00E+00
1,000	1.75E-02	6.25E-03	0.00E+00	1.75E-02	0.00E+00	0.00E+00	0.00E+00	3.93E-02	3.96E-02	1.37E-02	3.93E-02	0.00E+00	0.00E+00	0.00E+00
2,000	3.66E-02	1.39E-02	0.00E+00	3.66E-02	0.00E+00	2.73E-02	0.00E+00	8.02E-02	8.06E-02	3.68E-02	8.02E-02	0.00E+00	5.04E-03	0.00E+00
3,000	5.57E-02	2.16E-02	0.00E+00	5.57E-02	0.00E+00	5.99E-02	0.00E+00	1.21E-01	1.22E-01	5.99E-02	1.21E-01	0.00E+00	2.59E-02	0.00E+00
4,000	7.48E-02	2.92E-02	0.00E+00	7.48E-02	0.00E+00	9.25E-02	0.00E+00	1.62E-01	1.63E-01	8.30E-02	1.62E-01	0.00E+00	4.67E-02	0.00E+00
5,000	9.39E-02	3.69E-02	0.00E+00	9.39E-02	0.00E+00	1.25E-01	0.00E+00	2.03E-01	2.04E-01	1.06E-01	2.03E-01	6.92E-03	6.76E-02	0.00E+00
6,000	1.13E-01	4.45E-02	0.00E+00	1.13E-01	0.00E+00	1.58E-01	0.00E+00	2.44E-01	2.45E-01	1.29E-01	2.44E-01	2.61E-02	8.84E-02	0.00E+00
7,000	1.32E-01	5.22E-02	0.00E+00	1.32E-01	0.00E+00	1.90E-01	0.00E+00	2.85E-01	2.86E-01	1.52E-01	2.85E-01	4.52E-02	1.09E-01	5.00E-03
8,000	1.51E-01	5.99E-02	0.00E+00	1.51E-01	0.00E+00	2.23E-01	0.00E+00	3.26E-01	3.27E-01	1.75E-01	3.26E-01	6.44E-02	1.30E-01	1.49E-02
9,000	1.70E-01	6.75E-02	0.00E+00	1.70E-01	0.00E+00	2.55E-01	0.00E+00	3.67E-01	3.68E-01	1.98E-01	3.67E-01	8.35E-02	1.51E-01	2.48E-02
10,000	1.89E-01	7.52E-02	0.00E+00	1.89E-01	0.00E+00	2.88E-01	0.00E+00	4.08E-01	4.09E-01	2.21E-01	4.08E-01	1.03E-01	1.72E-01	3.47E-02

Time from Start of Operations (Years)*	Loading Calculations to Kasana (kg/year): Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	3.32E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	1.01E-04	0.00E+00	9.07E-05	0.00E+00	0.00E+00	0.00E+00	4.63E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	2.05E-04	0.00E+00	1.48E-04	0.00E+00	0.00E+00	0.00E+00	9.42E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	3.09E-04	0.00E+00	2.06E-04	0.00E+00	0.00E+00	0.00E+00	1.42E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	4.13E-04	0.00E+00	2.63E-04	0.00E+00	0.00E+00	0.00E+00	1.90E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	5.16E-04	1.74E-05	3.21E-04	0.00E+00	0.00E+00	0.00E+00	2.38E-08	1.37E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	6.20E-04	6.59E-05	3.78E-04	0.00E+00	0.00E+00	0.00E+00	2.86E-08	5.20E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	1.14E-03	3.09E-04	6.65E-04	0.00E+00	0.00E+00	0.00E+00	5.25E-08	2.43E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	1.66E-03	5.51E-04	9.53E-04	1.79E-05	0.00E+00	0.00E+00	7.65E-08	4.34E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	2.18E-03	7.94E-04	1.24E-03	7.16E-05	0.00E+00	0.00E+00	1.00E-07	6.26E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	2.70E-03	1.04E-03	1.53E-03	1.25E-04	0.00E+00	0.00E+00	1.24E-07	8.17E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	3.22E-03	1.28E-03	1.81E-03	1.79E-04	0.00E+00	0.00E+00	1.48E-07	1.01E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	3.74E-03	1.52E-03	2.10E-03	2.32E-04	0.00E+00	0.00E+00	1.72E-07	1.20E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	4.26E-03	1.76E-03	2.39E-03	2.86E-04	7.16E-05	0.00E+00	1.96E-07	1.39E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	4.78E-03	2.01E-03	2.68E-03	3.40E-04	1.52E-04	0.00E+00	2.20E-07	1.58E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	5.82E-03	2.49E-03	3.25E-03	4.47E-04	3.14E-04	0.00E+00	2.68E-07	1.96E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	6.86E-03	2.98E-03	3.83E-03	5.54E-04	4.76E-04	0.00E+00	3.16E-07	2.35E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	7.90E-03	3.46E-03	4.40E-03	6.62E-04	6.37E-04	0.00E+00	3.64E-07	2.73E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	8.94E-03	3.95E-03	4.98E-03	7.69E-04	7.99E-04	0.00E+00	4.12E-07	3.11E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	9.98E-03	4.43E-03	5.55E-03	8.76E-04	9.61E-04	0.00E+00	4.60E-07	3.49E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	2.04E-02	9.29E-03	1.13E-02	1.95E-03	2.58E-03	0.00E+00	9.39E-07	7.32E-09	0.00E+00	0.00E+00	1.05E-01	3.40E-02	0.00E+00	0.00E+00
3,000	3.08E-02	1.41E-02	1.70E-02	3.02E-03	4.19E-03	0.00E+00	1.42E-06	1.11E-08	0.00E+00	0.00E+00	2.30E-01	1.75E-01	0.00E+00	0.00E+00
4,000	4.12E-02	1.90E-02	2.28E-02	4.09E-03	5.81E-03	0.00E+00	1.90E-06	1.50E-08	0.00E+00	0.00E+00	3.55E-01	3.16E-01	0.00E+00	0.00E+00
5,000	5.16E-02	2.38E-02	2.85E-02	5.17E-03	7.43E-03	0.00E+00	2.38E-06	1.88E-08	0.00E+00	0.00E+00	4.79E-01	4.57E-01	0.00E+00	0.00E+00
6,000	6.20E-02	2.87E-02	3.43E-02	6.24E-03	9.04E-03	0.00E+00	2.85E-06	2.26E-08	0.00E+00	0.00E+00	6.04E-01	5.97E-01	0.00E+00	0.00E+00
7,000	7.24E-02	3.35E-02	4.00E-02	7.31E-03	1.07E-02	0.00E+00	3.33E-06	2.64E-08	0.00E+00	0.00E+00	7.29E-01	7.38E-01	3.38E-03	3.38E-02
8,000	8.28E-02	3.84E-02	4.58E-02	8.39E-03	1.23E-02	0.00E+00	3.81E-06	3.03E-08	0.00E+00	0.00E+00	8.54E-01	8.79E-01	1.01E-02	1.01E-01
9,000	9.32E-02	4.33E-02	5.15E-02	9.46E-03	1.39E-02	0.00E+00	4.29E-06	3.41E-08	0.00E+00	0.00E+00	9.79E-01	1.02E+00	1.68E-02	1.68E-01
10,000	1.04E-01	4.81E-02	5.73E-02	1.05E-02	1.55E-02	0.00E+00	4.77E-06	3.79E-08	0.00E+00	0.00E+00	1.10E+00	1.16E+00	2.34E-02	2.34E-01

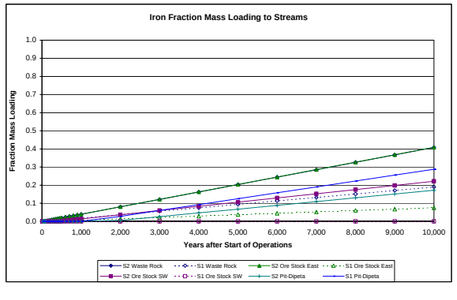
Ogata-Banks Solution, High V High C
Post-closure Loading to Dipeta, Scenario 1 (kg/yr)

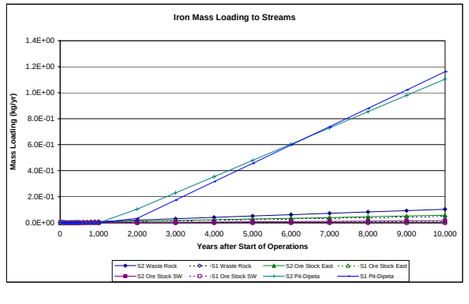
Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0
N/A	N/A	0
N/A	N/A	0
N/A	N/A	0
4.50E+01	0.0	0.00E+00
3.18E+01	0.0	0.00E+00
2.59E+01	0.0	0.00E+00
2.24E+01	0.0	0.00E+00
2.00E+01	0.0	0.00E+00
1.41E+01	0.0	0.00E+00
1.14E+01	0.0	0.00E+00
9.83E+00	0.0	0.00E+00
8.73E+00	0.0	0.00E+00
7.92E+00	0.0	0.00E+00
7.29E+00	0.0	0.00E+00
6.77E+00	0.0	0.00E+00
6.34E+00	0.0	0.00E+00
5.66E+00	0.0	0.00E+00
5.14E+00	0.0	0.00E+00
4.72E+00	0.0	0.00E+00
4.38E+00	0.0	0.00E+00
4.08E+00	0.0	0.00E+00
2.45E+00	0.0	0.00E+00
1.67E+00	0.0	3.49E-02
1.16E+00	0.1	1.92E-01
7.90E-01	0.3	5.06E-01
4.93E-01	0.5	9.32E-01
2.45E-01	0.7	1.40E+00
3.24E-02	1.0	1.85E+00
-1.55E-01	1.2	2.25E+00
-3.23E-01	1.4	2.59E+00

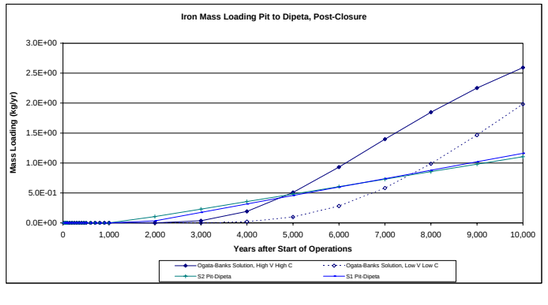
Ogata-Banks Solution, Low V Low C
Post-closure Loading to Dipeta, Scenario 2 (kg/yr)

Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0
N/A	N/A	0
N/A	N/A	0
N/A	N/A	0
5.63E+01	0.0	0.00E+00
3.98E+01	0.0	0.00E+00
3.24E+01	0.0	0.00E+00
2.81E+01	0.0	0.00E+00
2.51E+01	0.0	0.00E+00
1.77E+01	0.0	0.00E+00
1.44E+01	0.0	0.00E+00
1.24E+01	0.0	0.00E+00
1.10E+01	0.0	0.00E+00
1.00E+01	0.0	0.00E+00
9.26E+00	0.0	0.00E+00
8.62E+00	0.0	0.00E+00
8.10E+00	0.0	0.00E+00
7.26E+00	0.0	0.00E+00
6.63E+00	0.0	0.00E+00
6.12E+00	0.0	0.00E+00
5.70E+00	0.0	0.00E+00
5.35E+00	0.0	0.00E+00
3.41E+00	0.0	0.00E+00
2.52E+00	0.0	0.00E+00
1.95E+00	0.0	1.96E-02
1.54E+00	0.0	9.83E-02
1.23E+00	0.1	2.81E-01
9.65E-01	0.2	5.82E-01
7.45E-01	0.3	9.87E-01
5.54E-01	0.4	1.46E+00
3.84E-01	0.6	1.98E+00

* End of operational period: 16 years







DATA SHEET 10 - arsenic

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	926		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	112	52
	1	67,770	31,626
Ore Stockpile East	0	237	44
	1	169,067	31,559
Ore Stockpile Southwest	0	N/A	525
	1	N/A	56,545
Tailings Facility	0	112	52
	1	67,770	31,626
ROM Ore Stockpiles	0	N/A	5,998
	1	N/A	73,514
Pit to Dipeta	0	1,422	2,194
	1	41,119	64,220
Pit to Mofia	0	N/A	8,318
	1	N/A	138,912

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	202.012011	40808.85277	111.72855
	b	85.81	125.62	Scenario 2	138.000476	19044.13129	52.1399898
	c	-18527.6	-18527.6				
Full Contribution	a	0.03	0.06	Scenario 1	4975.24	24,753,019	67,770
	b	-85.81	-125.62	Scenario 2	3398.74	11,551,409	31,626
	c	-296441.6	-296441.6				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	294.219516	86,565	237
	b	59.21	137.05	Scenario 2	127.117359	16,159	44
	c	-18527.6	-18527.6				
Full Contribution	a	0.01	0.07	Scenario 1	7858.24	61,751,872	169,067
	b	-59.21	-137.05	Scenario 2	3395.15	11,527,016	31,559
	c	-324233	-324233				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	137.00	Scenario 2	437.70335	191,584	525
	c	-69478.5	-69478.5				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-137.00	Scenario 2	4544.55023	20,652,937	56,545
	c	-402975.3	-402975.3				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	202.012	40,809	112
	b	85.81	125.62	Scenario 2	138.0005	19,044	52
	c	-18527.6	-18527.6				
Full Contrib	a	0.03	0.06	Scenario 1	4975.241	24,753,019	67,770
	b	-85.81	-125.62	Scenario 2	3398.736	11,551,409	31,626
	c	-296441.6	-296441.6				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	176.86	Scenario 2	1480.068	2,190,602	5,998
	c	-370552	-370552				
Full Contrib	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-176.86	Scenario 2	5181.778	26,850,820	73,514
	c	-416871	-416871				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	707.949	501,192	1,422
	b	254.40	203.52	Scenario 2	884.9362	783,112	2,194
	c	-231595	-231595				
Full Contrib	a	0.10	0.07	Scenario 1	3873.02	15,000,310	41,119
	b	-254.40	-203.52	Scenario 2	4841.28	23,437,984	64,220
	c	-555828	-555828				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	195.12	Scenario 2	1737.827	3,020,044	8,318
	c	-463190	-463190				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-254.40	-195.12	Scenario 2	7121.75	50,719,305	138,912
	c	-694785	-694785				

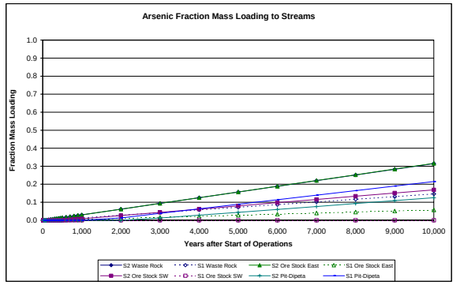
a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

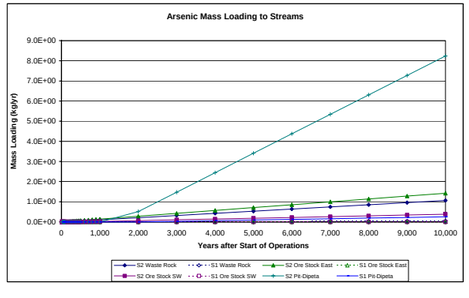
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.49E-04	5.00E-04	0.00E+00	2.49E-04	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.66E-04	8.17E-04	0.00E+00	5.66E-04	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.82E-04	1.13E-03	0.00E+00	8.82E-04	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-03	1.45E-03	0.00E+00	1.20E-03	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.52E-03	1.77E-03	0.00E+00	1.52E-03	0.00E+00	0.00E+00	0.00E+00
150	5.66E-04	0.00E+00	0.00E+00	5.66E-04	0.00E+00	0.00E+00	0.00E+00	3.10E-03	3.36E-03	0.00E+00	3.10E-03	0.00E+00	0.00E+00	0.00E+00
200	1.30E-03	0.00E+00	0.00E+00	1.30E-03	0.00E+00	0.00E+00	0.00E+00	4.68E-03	4.94E-03	0.00E+00	4.68E-03	0.00E+00	0.00E+00	0.00E+00
250	2.04E-03	7.70E-05	0.00E+00	2.04E-03	0.00E+00	0.00E+00	0.00E+00	6.27E-03	6.53E-03	0.00E+00	6.27E-03	0.00E+00	0.00E+00	0.00E+00
300	2.78E-03	3.73E-04	0.00E+00	2.78E-03	0.00E+00	0.00E+00	0.00E+00	7.85E-03	8.12E-03	0.00E+00	7.85E-03	0.00E+00	0.00E+00	0.00E+00
350	3.52E-03	6.69E-04	0.00E+00	3.52E-03	0.00E+00	0.00E+00	0.00E+00	9.43E-03	9.70E-03	0.00E+00	9.43E-03	0.00E+00	0.00E+00	0.00E+00
400	4.26E-03	9.65E-04	0.00E+00	4.26E-03	0.00E+00	0.00E+00	0.00E+00	1.10E-02	1.13E-02	0.00E+00	1.10E-02	0.00E+00	0.00E+00	0.00E+00
450	5.00E-03	1.26E-03	0.00E+00	5.00E-03	0.00E+00	0.00E+00	0.00E+00	1.26E-02	1.29E-02	0.00E+00	1.26E-02	0.00E+00	0.00E+00	0.00E+00
500	5.74E-03	1.56E-03	0.00E+00	5.74E-03	0.00E+00	0.00E+00	0.00E+00	1.42E-02	1.45E-02	0.00E+00	1.42E-02	0.00E+00	0.00E+00	0.00E+00
600	7.22E-03	2.15E-03	0.00E+00	7.22E-03	0.00E+00	0.00E+00	0.00E+00	1.74E-02	1.76E-02	1.35E-03	1.74E-02	0.00E+00	0.00E+00	0.00E+00
700	8.69E-03	2.74E-03	0.00E+00	8.69E-03	0.00E+00	0.00E+00	0.00E+00	2.05E-02	2.08E-02	3.13E-03	2.05E-02	0.00E+00	0.00E+00	0.00E+00
800	1.02E-02	3.33E-03	0.00E+00	1.02E-02	0.00E+00	0.00E+00	0.00E+00	2.37E-02	2.40E-02	4.92E-03	2.37E-02	0.00E+00	0.00E+00	0.00E+00
900	1.17E-02	3.93E-03	0.00E+00	1.17E-02	0.00E+00	0.00E+00	0.00E+00	2.69E-02	2.72E-02	6.70E-03	2.69E-02	0.00E+00	0.00E+00	0.00E+00
1,000	1.31E-02	4.52E-03	0.00E+00	1.31E-02	0.00E+00	0.00E+00	0.00E+00	3.00E-02	3.03E-02	8.49E-03	3.00E-02	0.00E+00	0.00E+00	0.00E+00
2,000	2.79E-02	1.04E-02	0.00E+00	2.79E-02	0.00E+00	1.33E-02	0.00E+00	6.17E-02	6.21E-02	2.63E-02	6.17E-02	0.00E+00	0.00E+00	0.00E+00
3,000	4.27E-02	1.64E-02	0.00E+00	4.27E-02	0.00E+00	3.85E-02	0.00E+00	9.34E-02	9.38E-02	4.42E-02	9.34E-02	0.00E+00	0.00E+00	0.00E+00
4,000	5.75E-02	2.23E-02	0.00E+00	5.75E-02	0.00E+00	6.37E-02	0.00E+00	1.25E-01	1.26E-01	6.20E-02	1.25E-01	0.00E+00	2.83E-02	0.00E+00
5,000	7.22E-02	2.82E-02	0.00E+00	7.22E-02	0.00E+00	8.89E-02	0.00E+00	1.57E-01	1.57E-01	7.99E-02	1.57E-01	0.00E+00	4.44E-02	0.00E+00
6,000	8.70E-02	3.41E-02	0.00E+00	8.70E-02	0.00E+00	1.14E-01	0.00E+00	1.88E-01	1.89E-01	9.77E-02	1.88E-01	3.64E-05	6.06E-02	0.00E+00
7,000	1.02E-01	4.01E-02	0.00E+00	1.02E-01	0.00E+00	1.39E-01	0.00E+00	2.20E-01	2.21E-01	1.16E-01	2.20E-01	1.48E-02	7.67E-02	0.00E+00
8,000	1.17E-01	4.60E-02	0.00E+00	1.17E-01	0.00E+00	1.64E-01	0.00E+00	2.52E-01	2.52E-01	1.33E-01	2.52E-01	2.97E-02	9.28E-02	0.00E+00
9,000	1.31E-01	5.19E-02	0.00E+00	1.31E-01	0.00E+00	1.90E-01	0.00E+00	2.83E-01	2.84E-01	1.51E-01	2.83E-01	4.45E-02	1.09E-01	4.84E-03
10,000	1.46E-01	5.78E-02	0.00E+00	1.46E-01	0.00E+00	2.15E-01	0.00E+00	3.15E-01	3.16E-01	1.69E-01	3.15E-01	5.93E-02	1.25E-01	1.25E-02

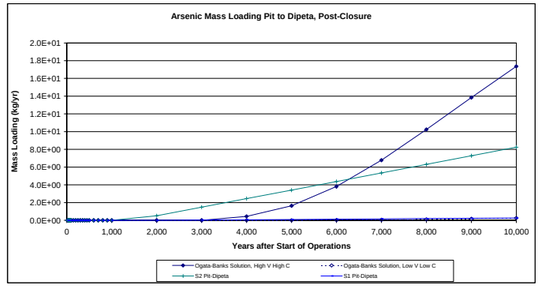
Loading Calculations to Kasana (kg/year)														
Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8.40E-04	0.00E+00	2.26E-03	0.00E+00	0.00E+00	0.00E+00	7.72E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.91E-03	0.00E+00	3.69E-03	0.00E+00	0.00E+00	0.00E+00	1.75E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.98E-03	0.00E+00	5.12E-03	0.00E+00	0.00E+00	0.00E+00	2.74E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.05E-03	0.00E+00	6.55E-03	0.00E+00	0.00E+00	0.00E+00	3.72E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5.12E-03	0.00E+00	7.98E-03	0.00E+00	0.00E+00	0.00E+00	4.70E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.05E-02	1.87E-04	1.51E-02	0.00E+00	0.00E+00	0.00E+00	9.62E-08	4.85E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.58E-02	4.31E-04	2.23E-02	0.00E+00	0.00E+00	0.00E+00	1.45E-07	1.12E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.12E-02	6.75E-04	2.95E-02	1.13E-05	0.00E+00	0.00E+00	1.94E-07	1.75E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.68E-02	9.13E-04	3.66E-02	5.49E-05	0.00E+00	0.00E+00	2.44E-07	2.38E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.19E-02	1.16E-03	4.38E-02	9.85E-05	0.00E+00	0.00E+00	2.93E-07	3.02E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3.72E-02	1.41E-03	5.09E-02	1.42E-04	0.00E+00	0.00E+00	3.42E-07	3.65E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.25E-02	1.65E-03	5.81E-02	1.86E-04	0.00E+00	0.00E+00	3.91E-07	4.28E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.79E-02	1.89E-03	6.52E-02	2.29E-04	0.00E+00	0.00E+00	4.40E-07	4.92E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5.86E-02	2.38E-03	7.96E-02	3.16E-04	3.04E-03	0.00E+00	5.38E-07	6.18E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6.93E-02	2.87E-03	9.39E-02	4.03E-04	7.07E-03	0.00E+00	6.37E-07	7.45E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8.00E-02	3.36E-03	1.08E-01	4.91E-04	1.11E-02	0.00E+00	7.35E-07	8.72E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9.07E-02	3.85E-03	1.22E-01	5.78E-04	1.51E-02	0.00E+00	8.33E-07	9.98E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.01E-01	4.33E-03	1.37E-01	6.65E-04	1.91E-02	0.00E+00	9.31E-07	1.12E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.08E-01	9.21E-03	2.80E-01	1.54E-03	5.94E-02	0.00E+00	1.91E-06	2.39E-08	0.00E+00	0.00E+00	5.10E-01	0.00E+00	0.00E+00	0.00E+00
3.15E-01	1.41E-02	4.23E-01	2.41E-03	9.97E-02	0.00E+00	2.90E-06	3.66E-08	0.00E+00	0.00E+00	1.48E+00	2.47E-02	0.00E+00	0.00E+00
4.22E-01	1.90E-02	5.66E-01	3.28E-03	1.40E-01	0.00E+00	3.88E-06	4.92E-08	0.00E+00	0.00E+00	2.44E+00	5.74E-02	0.00E+00	0.00E+00
5.29E-01	2.38E-02	7.09E-01	4.15E-03	1.80E-01	0.00E+00	4.86E-06	6.19E-08	0.00E+00	0.00E+00	3.41E+00	9.01E-02	0.00E+00	0.00E+00
6.36E-01	2.87E-02	8.53E-01	5.02E-03	2.20E-01	0.00E+00	5.84E-06	7.46E-08	0.00E+00	0.00E+00	4.37E+00	1.23E-01	0.00E+00	0.00E+00
7.43E-01	3.36E-02	9.96E-01	5.89E-03	2.61E-01	0.00E+00	6.83E-06	8.72E-08	0.00E+00	0.00E+00	5.34E+00	1.55E-01	0.00E+00	0.00E+00
8.50E-01	3.85E-02	1.14E+00	6.76E-03	3.01E-01	0.00E+00	7.81E-06	9.99E-08	0.00E+00	0.00E+00	6.31E+00	1.88E-01	0.00E+00	0.00E+00
9.57E-01	4.34E-02	1.28E+00	7.64E-03	3.41E-01	0.00E+00	8.79E-06	1.13E-07	0.00E+00	0.00E+00	7.27E+00	2.21E-01	3.27E-02	9.80E-03
1.06E+00	4.82E-02	1.43E+00	8.51E-03	3.82E-01	0.00E+00	9.77E-06	1.25E-07	0.00E+00	0.00E+00	8.24E+00	2.53E-01	8.44E-02	2.53E-02

Ogata-Banks Solution, High V High C — Post-closure Loading to Dipeta, Scenario 1 (kg/yr)				Ogata-Banks Solution, Low V Low C — Post-closure Loading to Dipeta, Scenario 2 (kg/yr)			
Beta	erfc (Beta)		Mass Loading (kg/yr)	Beta	erfc (Beta)		Mass Loading (kg/yr)
N/A	N/A	0		N/A	N/A	0	
N/A	N/A	0		N/A	N/A	0	
N/A	N/A	0		N/A	N/A	0	
N/A	N/A	0		N/A	N/A	0	
5.12E+01	0.0	0.00E+00		6.40E+01	0.0	0.00E+00	
3.62E+01	0.0	0.00E+00		4.52E+01	0.0	0.00E+00	
2.95E+01	0.0	0.00E+00		3.69E+01	0.0	0.00E+00	
2.55E+01	0.0	0.00E+00		3.19E+01	0.0	0.00E+00	
2.28E+01	0.0	0.00E+00		2.86E+01	0.0	0.00E+00	
1.60E+01	0.0	0.00E+00		2.01E+01	0.0	0.00E+00	
1.30E+01	0.0	0.00E+00		1.64E+01	0.0	0.00E+00	
1.12E+01	0.0	0.00E+00		1.41E+01	0.0	0.00E+00	
1.00E+01	0.0	0.00E+00		1.26E+01	0.0	0.00E+00	
9.09E+00	0.0	0.00E+00		1.15E+01	0.0	0.00E+00	
8.37E+00	0.0	0.00E+00		1.06E+01	0.0	0.00E+00	
7.79E+00	0.0	0.00E+00		9.88E+00	0.0	0.00E+00	
7.31E+00	0.0	0.00E+00		9.28E+00	0.0	0.00E+00	
6.55E+00	0.0	0.00E+00		8.35E+00	0.0	0.00E+00	
5.96E+00	0.0	0.00E+00		7.63E+00	0.0	0.00E+00	
5.49E+00	0.0	0.00E+00		7.06E+00	0.0	0.00E+00	
5.11E+00	0.0	0.00E+00		6.59E+00	0.0	0.00E+00	
4.78E+00	0.0	0.00E+00		6.19E+00	0.0	0.00E+00	
2.99E+00	0.0	0.00E+00		4.04E+00	0.0	0.00E+00	
2.14E+00	0.0	0.00E+00		3.06E+00	0.0	0.00E+00	
1.61E+00	0.0	4.41E-01		2.45E+00	0.0	0.00E+00	
1.22E+00	0.1	1.64E+00		2.01E+00	0.0	0.00E+00	
9.09E-01	0.2	3.81E+00		1.67E+00	0.0	1.83E-02	
6.56E-01	0.4	6.78E+00		1.40E+00	0.0	4.85E-02	
4.40E-01	0.5	1.02E+01		1.17E+00	0.1	9.94E-02	
2.52E-01	0.7	1.38E+01		9.72E-01	0.2	1.72E-01	
8.39E-02	0.9	1.74E+01		7.98E-01	0.3	2.63E-01	

* End of operational period: 16 years







DATA SHEET 11 - manganese

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	1208		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation **16**
Years to Pit Flow-Through **50**

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	146	68
	1	88,358	41,234
Ore Stockpile East	0	309	58
	1	220,429	41,147
Ore Stockpile Southwest	0	N/A	684
	1	N/A	73,723
Tailings Facility	0	146	68
	1	88,358	41,234
ROM Ore Stockpiles	0	N/A	7,820
	1	N/A	95,847
Pit to Dipeta	0	1,839	2,845
	1	53,595	83,714
Pit to Mofia	0	N/A	10,830
	1	N/A	181,097

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	230.665115	53206.39528	145.671171
	b	97.98	143.43	Scenario 2	157.574272	24829.65113	67.9798799
	c	-24156.2	-24156.2				
Full Contribution	a	0.03	0.06	Scenario 1	5680.92	32,272,873	88,358
	b	-97.98	-143.43	Scenario 2	3880.81	15,060,674	41,234
	c	-386499.2	-386499.2				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	335.951204	112,863	309
	b	67.61	156.48	Scenario 2	145.147509	21,068	58
	c	-24156.2	-24156.2				
Full Contribution	a	0.01	0.07	Scenario 1	8972.84	80,511,808	220,429
	b	-67.61	-156.48	Scenario 2	3876.71	15,028,871	41,147
	c	-422733.5	-422733.5				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	156.43	Scenario 2	499.786587	249,787	684
	c	-90585.75	-90585.75				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-156.43	Scenario 2	5189.14293	26,927,204	73,723
	c	-525397.35	-525397.35				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	230.6651	53,206	146
	b	97.98	143.43	Scenario 2	157.5743	24,830	68
	c	-24156.2	-24156.2				
Full Contribution	a	0.03	0.06	Scenario 1	5680.922	32,272,873	88,358
	b	-97.98	-143.43	Scenario 2	3880.808	15,060,674	41,234
	c	-386499.2	-386499.2				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	201.95	Scenario 2	1689.999	2,856,097	7,820
	c	-483124	-483124				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-201.95	Scenario 2	5916.754	35,007,976	95,847
	c	-543514.5	-543514.5				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	808.3635	653,452	1,839
	b	290.48	232.39	Scenario 2	1010.454	1,021,018	2,845
	c	-301952.5	-301952.5				
Full Contribution	a	0.10	0.07	Scenario 1	4422.37	19,557,335	53,595
	b	-290.48	-232.39	Scenario 2	5527.96	30,558,336	83,714
	c	-724686	-724686				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	222.79	Scenario 2	1984.318	3,937,519	10,830
	c	-603905	-603905				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-290.48	-222.79	Scenario 2	8131.89	66,127,598	181,097
	c	-905857.5	-905857.5				

Scenario 1

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	4.91E-05	0.00E+00	0.00E+00	4.91E-05	0.00E+00	0.00E+00	0.00E+00
200	6.16E-04	0.00E+00	0.00E+00	6.16E-04	0.00E+00	0.00E+00	0.00E+00
250	1.18E-03	0.00E+00	0.00E+00	1.18E-03	0.00E+00	0.00E+00	0.00E+00
300	1.75E-03	0.00E+00	0.00E+00	1.75E-03	0.00E+00	0.00E+00	0.00E+00
350	2.32E-03	1.86E-04	0.00E+00	2.32E-03	0.00E+00	0.00E+00	0.00E+00
400	2.88E-03	4.13E-04	0.00E+00	2.88E-03	0.00E+00	0.00E+00	0.00E+00
450	3.45E-03	6.41E-04	0.00E+00	3.45E-03	0.00E+00	0.00E+00	0.00E+00
500	4.02E-03	8.68E-04	0.00E+00	4.02E-03	0.00E+00	0.00E+00	0.00E+00
600	5.15E-03	1.32E-03	0.00E+00	5.15E-03	0.00E+00	0.00E+00	0.00E+00
700	6.28E-03	1.78E-03	0.00E+00	6.28E-03	0.00E+00	0.00E+00	0.00E+00
800	7.42E-03	2.23E-03	0.00E+00	7.42E-03	0.00E+00	0.00E+00	0.00E+00
900	8.55E-03	2.68E-03	0.00E+00	8.55E-03	0.00E+00	0.00E+00	0.00E+00
1,000	9.68E-03	3.14E-03	0.00E+00	9.68E-03	0.00E+00	0.00E+00	0.00E+00
2,000	2.10E-02	7.68E-03	0.00E+00	2.10E-02	0.00E+00	2.14E-03	0.00E+00
3,000	3.24E-02	1.22E-02	0.00E+00	3.24E-02	0.00E+00	2.15E-02	0.00E+00
4,000	4.37E-02	1.68E-02	0.00E+00	4.37E-02	0.00E+00	4.08E-02	0.00E+00
5,000	5.50E-02	2.13E-02	0.00E+00	5.50E-02	0.00E+00	6.01E-02	0.00E+00
6,000	6.64E-02	2.59E-02	0.00E+00	6.64E-02	0.00E+00	7.94E-02	0.00E+00
7,000	7.77E-02	3.04E-02	0.00E+00	7.77E-02	0.00E+00	9.88E-02	0.00E+00
8,000	8.90E-02	3.49E-02	0.00E+00	8.90E-02	0.00E+00	1.18E-01	0.00E+00
9,000	1.00E-01	3.95E-02	0.00E+00	1.00E-01	0.00E+00	1.37E-01	0.00E+00
10,000	1.12E-01	4.40E-02	0.00E+00	1.12E-01	0.00E+00	1.57E-01	0.00E+00

Scenario 2

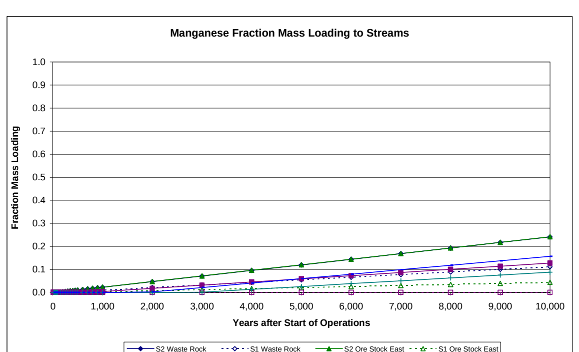
Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	5.65E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	4.91E-05	3.00E-04	0.00E+00	4.91E-05	0.00E+00	0.00E+00	0.00E+00
80	2.92E-04	5.43E-04	0.00E+00	2.92E-04	0.00E+00	0.00E+00	0.00E+00
90	5.35E-04	7.87E-04	0.00E+00	5.35E-04	0.00E+00	0.00E+00	0.00E+00
100	7.78E-04	1.03E-03	0.00E+00	7.78E-04	0.00E+00	0.00E+00	0.00E+00
150	1.99E-03	2.25E-03	0.00E+00	1.99E-03	0.00E+00	0.00E+00	0.00E+00
200	3.21E-03	3.46E-03	0.00E+00	3.21E-03	0.00E+00	0.00E+00	0.00E+00
250	4.42E-03	4.68E-03	0.00E+00	4.42E-03	0.00E+00	0.00E+00	0.00E+00
300	5.64E-03	5.90E-03	0.00E+00	5.64E-03	0.00E+00	0.00E+00	0.00E+00
350	6.85E-03	7.11E-03	0.00E+00	6.85E-03	0.00E+00	0.00E+00	0.00E+00
400	8.07E-03	8.33E-03	0.00E+00	8.07E-03	0.00E+00	0.00E+00	0.00E+00
450	9.28E-03	9.55E-03	0.00E+00	9.28E-03	0.00E+00	0.00E+00	0.00E+00
500	1.05E-02	1.08E-02	0.00E+00	1.05E-02	0.00E+00	0.00E+00	0.00E+00
600	1.29E-02	1.32E-02	0.00E+00	1.29E-02	0.00E+00	0.00E+00	0.00E+00
700	1.54E-02	1.56E-02	2.21E-04	1.54E-02	0.00E+00	0.00E+00	0.00E+00
800	1.78E-02	1.81E-02	1.59E-03	1.78E-02	0.00E+00	0.00E+00	0.00E+00
900	2.02E-02	2.05E-02	2.96E-03	2.02E-02	0.00E+00	0.00E+00	0.00E+00
1,000	2.26E-02	2.29E-02	4.33E-03	2.26E-02	0.00E+00	0.00E+00	0.00E+00
2,000	4.69E-02	4.73E-02	1.80E-02	4.69E-02	0.00E+00	0.00E+00	0.00E+00
3,000	7.12E-02	7.16E-02	3.17E-02	7.12E-02	0.00E+00	1.29E-03	0.00E+00
4,000	9.55E-02	9.59E-02	4.54E-02	9.55E-02	0.00E+00	1.37E-02	0.00E+00
5,000	1.20E-01	1.20E-01	5.91E-02	1.20E-01	0.00E+00	2.60E-02	0.00E+00
6,000	1.44E-01	1.45E-01	7.28E-02	1.44E-01	0.00E+00	3.84E-02	0.00E+00
7,000	1.68E-01	1.69E-01	8.65E-02	1.68E-01	0.00E+00	5.08E-02	0.00E+00
8,000	1.93E-01	1.93E-01	1.00E-01	1.93E-01	2.05E-03	6.31E-02	0.00E+00
9,000	2.17E-01	2.18E-01	1.14E-01	2.17E-01	1.34E-02	7.55E-02	0.00E+00
10,000	2.41E-01	2.42E-01	1.28E-01	2.41E-01	2.48E-02	8.79E-02	0.00E+00

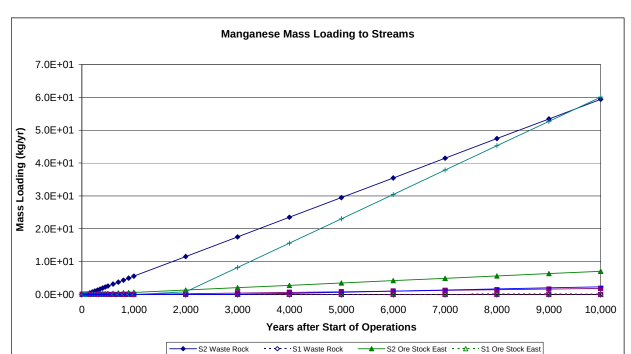
Loading Calculations to Kasana (kg/year)

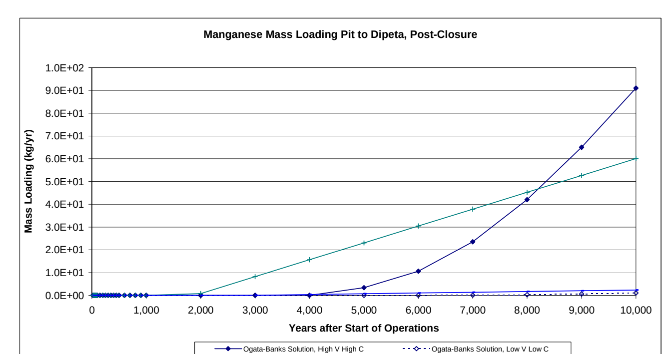
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	1.65E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	1.21E-02	0.00E+00	8.77E-03	0.00E+00	0.00E+00	0.00E+00	6.20E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	7.19E-02	0.00E+00	1.59E-02	0.00E+00	0.00E+00	0.00E+00	3.69E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	1.32E-01	0.00E+00	2.30E-02	0.00E+00	0.00E+00	0.00E+00	6.76E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	1.92E-01	0.00E+00	3.01E-02	0.00E+00	0.00E+00	0.00E+00	9.82E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	4.91E-01	5.06E-05	6.57E-02	0.00E+00	0.00E+00	0.00E+00	2.52E-08	1.93E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	7.90E-01	6.35E-04	1.01E-01	0.00E+00	0.00E+00	0.00E+00	4.05E-08	2.43E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	1.09E+00	1.22E-03	1.37E-01	0.00E+00	0.00E+00	0.00E+00	5.59E-08	4.66E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	1.39E+00	1.80E-03	1.72E-01	0.00E+00	0.00E+00	0.00E+00	7.12E-08	6.89E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	1.69E+00	2.39E-03	2.08E-01	3.55E-04	0.00E+00	0.00E+00	8.65E-08	9.12E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	1.99E+00	2.97E-03	2.44E-01	7.88E-04	0.00E+00	0.00E+00	1.02E-07	1.14E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	2.29E+00	3.56E-03	2.79E-01	1.22E-03	0.00E+00	0.00E+00	1.17E-07	1.36E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	2.58E+00	4.14E-03	3.15E-01	1.65E-03	0.00E+00	0.00E+00	1.33E-07	1.58E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	3.18E+00	5.31E-03	3.86E-01	2.52E-03	0.00E+00	0.00E+00	1.63E-07	2.03E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	3.78E+00	6.48E-03	4.57E-01	3.38E-03	3.23E-03	0.00E+00	1.94E-07	2.47E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	4.38E+00	7.64E-03	5.28E-01	4.25E-03	2.32E-02	0.00E+00	2.25E-07	2.92E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	4.98E+00	8.81E-03	5.99E-01	5.12E-03	4.33E-02	0.00E+00	2.55E-07	3.37E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	5.58E+00	9.98E-03	6.70E-01	5.98E-03	6.33E-02	0.00E+00	2.86E-07	3.81E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	1.16E+01	2.17E-02	1.38E+00	1.46E-02	2.63E-01	0.00E+00	5.93E-07	8.28E-09	0.00E+00	0.00E+00	8.22E-01	0.00E+00	0.00E+00	0.00E+00
3,000	1.75E+01	3.33E-02	2.09E+00	2.33E-02	4.64E-01	0.00E+00	9.00E-07	1.27E-08	0.00E+00	0.00E+00	8.23E+00	3.50E-02	0.00E+00	0.00E+00
4,000	2.35E+01	4.50E-02	2.81E+00	3.19E-02	6.64E-01	0.00E+00	1.21E-06	1.72E-08	0.00E+00	0.00E+00	1.56E+01	3.69E-01	0.00E+00	0.00E+00
5,000	2.95E+01	5.67E-02	3.52E+00	4.06E-02	8.64E-01	0.00E+00	1.51E-06	2.17E-08	0.00E+00	0.00E+00	2.31E+01	7.03E-01	0.00E+00	0.00E+00
6,000	3.55E+01	6.84E-02	4.23E+00	4.93E-02	1.06E+00	0.00E+00	1.82E-06	2.61E-08	0.00E+00	0.00E+00	3.05E+01	1.04E+00	0.00E+00	0.00E+00
7,000	4.15E+01	8.01E-02	4.94E+00	5.79E-02	1.26E+00	0.00E+00	2.13E-06	3.06E-08	0.00E+00	0.00E+00	3.79E+01	1.37E+00	0.00E+00	0.00E+00
8,000	4.75E+01	9.18E-02	5.65E+00	6.66E-02	1.46E+00	0.00E+00	2.43E-06	3.51E-08	0.00E+00	0.00E+00	4.53E+01	1.71E+00	0.00E+00	0.00E+00
9,000	5.34E+01	1.03E-01	6.36E+00	7.52E-02	1.66E+00	0.00E+00	2.74E-06	3.95E-08	0.00E+00	0.00E+00	5.27E+01	2.04E+00	0.00E+00	0.00E+00
10,000	5.94E+01	1.15E-01	7.07E+00	8.39E-02	1.86E+00	0.00E+00	3.05E-06	4.40E-08	0.00E+00	0.00E+00	6.01E+01	2.37E+00	0.00E+00	0.00E+00

* End of operational period: 16 years

Time from Start of Operations (Years)*	Ogata-Banks Solution, High V High C — Post-closure Loading to Dipeta, Scenario 1 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)	Ogata-Banks Solution, Low V Low C — Post-closure Loading to Dipeta, Scenario 2 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)
20	N/A	N/A	0	N/A	N/A	0
30	N/A	N/A	0	N/A	N/A	0
40	N/A	N/A	0	N/A	N/A	0
50	N/A	N/A	0	N/A	N/A	0
60	5.85E+01	0.0	0.00E+00	7.31E+01	0.0	0.00E+00
70	4.13E+01	0.0	0.00E+00	5.17E+01	0.0	0.00E+00
80	3.37E+01	0.0	0.00E+00	4.22E+01	0.0	0.00E+00
90	2.92E+01	0.0	0.00E+00	3.65E+01	0.0	0.00E+00
100	2.61E+01	0.0	0.00E+00	3.26E+01	0.0	0.00E+00
150	1.84E+01	0.0	0.00E+00	2.30E+01	0.0	0.00E+00
200	1.49E+01	0.0	0.00E+00	1.87E+01	0.0	0.00E+00
250	1.29E+01	0.0	0.00E+00	1.62E+01	0.0	0.00E+00
300	1.15E+01	0.0	0.00E+00	1.45E+01	0.0	0.00E+00
350	1.04E+01	0.0	0.00E+00	1.32E+01	0.0	0.00E+00
400	9.64E+00	0.0	0.00E+00	1.22E+01	0.0	0.00E+00
450	8.98E+00	0.0	0.00E+00	1.13E+01	0.0	0.00E+00
500	8.43E+00	0.0	0.00E+00	1.07E+01	0.0	0.00E+00
600	7.57E+00	0.0	0.00E+00	9.61E+00	0.0	0.00E+00
700	6.91E+00	0.0	0.00E+00	8.79E+00	0.0	0.00E+00
800	6.38E+00	0.0	0.00E+00	8.15E+00	0.0	0.00E+00
900	5.95E+00	0.0	0.00E+00	7.62E+00	0.0	0.00E+00
1,000	5.59E+00	0.0	0.00E+00	7.17E+00	0.0	0.00E+00
2,000	3.59E+00	0.0	0.00E+00	4.76E+00	0.0	0.00E+00
3,000	2.67E+00	0.0	0.00E+00	3.67E+00	0.0	0.00E+00
4,000	2.09E+00	0.0	0.00E+00	3.00E+00	0.0	0.00E+00
5,000	1.68E+00	0.0	3.38E+00	2.53E+00	0.0	0.00E+00
6,000	1.36E+00	0.1	1.06E+01	2.16E+00	0.0	0.00E+00
7,000	1.09E+00	0.1	2.35E+01	1.87E+00	0.0	1.10E-01
8,000	8.69E-01	0.2	4.20E+01	1.63E+00	0.0	2.87E-01
9,000	6.76E-01	0.3	6.50E+01	1.42E+00	0.0	6.02E-01
10,000	5.06E-01	0.5	9.10E+01	1.24E+00	0.1	1.08E+00







DATA SHEET 12 - uranium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	2386		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	288	134
	1	174,550	81,457
Ore Stockpile East	0	610	114
	1	435,453	81,285
Ore Stockpile Southwest	0	N/A	1,351
	1	N/A	145,637
Tailings Facility	0	288	134
	1	174,550	81,457
ROM Ore Stockpiles	0	N/A	15,447
	1	N/A	189,343
Pit to Dipeta	0	3,584	5,572
	1	105,827	165,327
Pit to Mofia	0	N/A	21,346
	1	N/A	357,705

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	324.203596	105107.9716	287.769943
	b	137.72	201.60	Scenario 2	221.473219	49050.38673	134.29264
	c	-47720	-47720				
Full Contribution	a	0.03	0.06	Scenario 1	7984.63	63,754,296	174,550
	b	-137.72	-201.60	Scenario 2	5454.54	29,752,005	81,457
	c	-763520	-763520				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	472.184917	222,959	610
	b	95.03	219.94	Scenario 2	204.007201	41,619	114
	c	-47720	-47720				
Full Contribution	a	0.01	0.07	Scenario 1	12611.47	159,049,167	435,453
	b	-95.03	-219.94	Scenario 2	5448.78	29,689,178	81,285
	c	-835100	-835100				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	219.87	Scenario 2	702.458231	493,448	1,351
	c	-178950	-178950				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-219.87	Scenario 2	7293.42535	53,194,053	145,637
	c	-1037910	-1037910				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	324.2036	105,108	288
	b	137.72	201.60	Scenario 2	221.4732	49,050	134
	c	-47720	-47720				
Full Contribution	a	0.03	0.06	Scenario 1	7984.629	63,754,296	174,550
	b	-137.72	-201.60	Scenario 2	5454.54	29,752,005	81,457
	c	-763520	-763520				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	283.85	Scenario 2	2375.321	5,642,152	15,447
	c	-954400	-954400				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-283.85	Scenario 2	8316.094	69,157,426	189,343
	c	-1073700	-1073700				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	1136.168	1,290,878	3,584
	b	408.28	326.62	Scenario 2	1420.21	2,016,997	5,572
	c	-596500	-596500				
Full Contribution	a	0.10	0.07	Scenario 1	6215.71	38,635,052	105,827
	b	-408.28	-326.62	Scenario 2	7769.64	60,367,268	165,327
	c	-1431600	-1431600				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	313.14	Scenario 2	2788.992	7,778,476	21,346
	c	-1193000	-1193000				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-408.28	-313.14	Scenario 2	11429.50	130,633,500	357,705
	c	-1789500	-1789500				

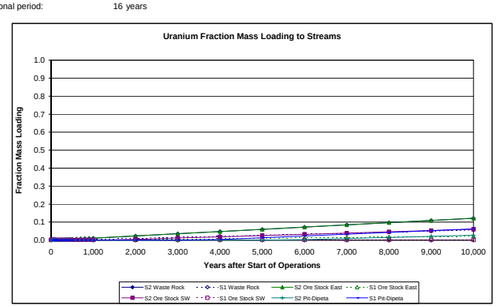
a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

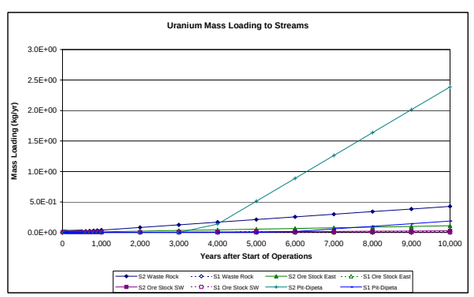
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.08E-04	1.06E-03	0.00E+00	8.08E-04	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-03	1.68E-03	0.00E+00	1.42E-03	0.00E+00	0.00E+00	0.00E+00
300	7.02E-05	0.00E+00	0.00E+00	7.02E-05	0.00E+00	0.00E+00	0.00E+00	2.04E-03	2.29E-03	0.00E+00	2.04E-03	0.00E+00	0.00E+00	0.00E+00
350	3.57E-04	0.00E+00	0.00E+00	3.57E-04	0.00E+00	0.00E+00	0.00E+00	2.65E-03	2.91E-03	0.00E+00	2.65E-03	0.00E+00	0.00E+00	0.00E+00
400	6.44E-04	0.00E+00	0.00E+00	6.44E-04	0.00E+00	0.00E+00	0.00E+00	3.27E-03	3.52E-03	0.00E+00	3.27E-03	0.00E+00	0.00E+00	0.00E+00
450	9.31E-04	0.00E+00	0.00E+00	9.31E-04	0.00E+00	0.00E+00	0.00E+00	3.88E-03	4.14E-03	0.00E+00	3.88E-03	0.00E+00	0.00E+00	0.00E+00
500	1.22E-03	0.00E+00	0.00E+00	1.22E-03	0.00E+00	0.00E+00	0.00E+00	4.50E-03	4.76E-03	0.00E+00	4.50E-03	0.00E+00	0.00E+00	0.00E+00
600	1.79E-03	0.00E+00	0.00E+00	1.79E-03	0.00E+00	0.00E+00	0.00E+00	5.73E-03	5.99E-03	0.00E+00	5.73E-03	0.00E+00	0.00E+00	0.00E+00
700	2.37E-03	2.06E-04	0.00E+00	2.37E-03	0.00E+00	0.00E+00	0.00E+00	6.96E-03	7.22E-03	0.00E+00	6.96E-03	0.00E+00	0.00E+00	0.00E+00
800	2.94E-03	4.36E-04	0.00E+00	2.94E-03	0.00E+00	0.00E+00	0.00E+00	8.19E-03	8.45E-03	0.00E+00	8.19E-03	0.00E+00	0.00E+00	0.00E+00
900	3.51E-03	6.66E-04	0.00E+00	3.51E-03	0.00E+00	0.00E+00	0.00E+00	9.42E-03	9.68E-03	0.00E+00	9.42E-03	0.00E+00	0.00E+00	0.00E+00
1,000	4.09E-03	8.96E-04	0.00E+00	4.09E-03	0.00E+00	0.00E+00	0.00E+00	1.06E-02	1.09E-02	0.00E+00	1.06E-02	0.00E+00	0.00E+00	0.00E+00
2,000	9.83E-03	3.20E-03	0.00E+00	9.83E-03	0.00E+00	0.00E+00	0.00E+00	2.29E-02	2.32E-02	4.50E-03	2.29E-02	0.00E+00	0.00E+00	0.00E+00
3,000	1.56E-02	5.50E-03	0.00E+00	1.56E-02	0.00E+00	0.00E+00	0.00E+00	3.52E-02	3.56E-02	1.14E-02	3.52E-02	0.00E+00	0.00E+00	0.00E+00
4,000	2.13E-02	7.79E-03	0.00E+00	2.13E-02	0.00E+00	3.58E-03	0.00E+00	4.75E-02	4.79E-02	1.84E-02	4.75E-02	0.00E+00	0.00E+00	0.00E+00
5,000	2.70E-02	1.01E-02	0.00E+00	2.70E-02	0.00E+00	1.34E-02	0.00E+00	5.98E-02	6.02E-02	2.53E-02	5.98E-02	0.00E+00	0.00E+00	0.00E+00
6,000	3.28E-02	1.24E-02	0.00E+00	3.28E-02	0.00E+00	2.31E-02	0.00E+00	7.21E-02	7.25E-02	3.22E-02	7.21E-02	0.00E+00	2.36E-03	0.00E+00
7,000	3.85E-02	1.47E-02	0.00E+00	3.85E-02	0.00E+00	3.29E-02	0.00E+00	8.44E-02	8.48E-02	3.92E-02	8.44E-02	0.00E+00	8.62E-03	0.00E+00
8,000	4.43E-02	1.70E-02	0.00E+00	4.43E-02	0.00E+00	4.27E-02	0.00E+00	9.67E-02	9.72E-02	4.61E-02	9.67E-02	0.00E+00	1.49E-02	0.00E+00
9,000	5.00E-02	1.93E-02	0.00E+00	5.00E-02	0.00E+00	5.25E-02	0.00E+00	1.09E-01	1.09E-01	5.30E-02	1.09E-01	0.00E+00	2.11E-02	0.00E+00
10,000	5.57E-02	2.16E-02	0.00E+00	5.57E-02	0.00E+00	6.23E-02	0.00E+00	1.21E-01	1.22E-01	5.99E-02	1.21E-01	0.00E+00	2.74E-02	0.00E+00

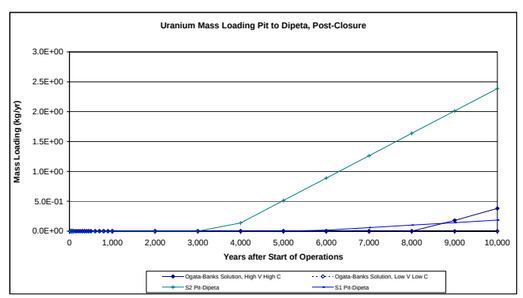
Loading Calculations to Kasana (kg/year)	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	6.82E-04	0.00E+00	3.98E-04	0.00E+00	0.00E+00	0.00E+00	1.11E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	2.85E-03	0.00E+00	9.51E-04	0.00E+00	0.00E+00	0.00E+00	4.65E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	5.02E-03	0.00E+00	1.50E-03	0.00E+00	0.00E+00	0.00E+00	8.19E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	7.20E-03	2.36E-05	2.06E-03	0.00E+00	0.00E+00	0.00E+00	1.17E-09	1.40E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	9.37E-03	1.20E-04	2.61E-03	0.00E+00	0.00E+00	0.00E+00	1.53E-09	7.15E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	1.15E-02	2.17E-04	3.16E-03	0.00E+00	0.00E+00	0.00E+00	1.88E-09	1.29E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	1.37E-02	3.13E-04	3.71E-03	0.00E+00	0.00E+00	0.00E+00	2.23E-09	1.86E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	1.59E-02	4.10E-04	4.26E-03	0.00E+00	0.00E+00	0.00E+00	2.59E-09	2.44E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	2.02E-02	6.03E-04	5.37E-03	0.00E+00	0.00E+00	0.00E+00	3.30E-09	3.59E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	2.46E-02	7.96E-04	6.47E-03	1.13E-04	0.00E+00	0.00E+00	4.00E-09	4.73E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	2.89E-02	9.90E-04	7.58E-03	2.38E-04	0.00E+00	0.00E+00	4.71E-09	5.88E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	3.33E-02	1.18E-03	8.68E-03	3.64E-04	0.00E+00	0.00E+00	5.42E-09	7.03E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	7.76E-02	1.38E-03	9.79E-03	4.89E-04	0.00E+00	0.00E+00	6.13E-09	8.18E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	8.10E-02	3.31E-03	2.08E-02	1.75E-03	2.02E-03	0.00E+00	1.32E-08	1.97E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	1.24E-01	5.24E-03	3.19E-02	3.00E-03	5.12E-03	0.00E+00	2.03E-08	3.11E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	1.68E-01	7.17E-03	4.29E-02	4.26E-03	8.23E-03	0.00E+00	2.74E-08	4.26E-09	0.00E+00	0.00E+00	1.37E-01	0.00E+00	0.00E+00	0.00E+00
6,000	2.11E-01	9.10E-03	5.40E-02	5.52E-03	1.13E-02	0.00E+00	3.44E-08	5.41E-09	0.00E+00	0.00E+00	5.12E-01	0.00E+00	0.00E+00	0.00E+00
7,000	2.55E-01	1.10E-02	6.50E-02	6.77E-03	1.44E-02	0.00E+00	4.15E-08	6.56E-09	0.00E+00	0.00E+00	8.87E-01	1.60E-02	0.00E+00	0.00E+00
8,000	2.98E-01	1.30E-02	7.61E-02	8.03E-03	1.76E-02	0.00E+00	4.86E-08	7.71E-09	0.00E+00	0.00E+00	1.26E+00	5.83E-02	0.00E+00	0.00E+00
9,000	3.42E-01	1.49E-02	8.71E-02	9.28E-03	2.07E-02	0.00E+00	5.57E-08	8.86E-09	0.00E+00	0.00E+00	1.64E+00	1.01E-01	0.00E+00	0.00E+00
10,000	3.85E-01	1.68E-02	9.82E-02	1.05E-02	2.38E-02	0.00E+00	6.27E-08	1.00E-08	0.00E+00	0.00E+00	2.01E+00	1.43E-01	0.00E+00	0.00E+00
	4.28E-01	1.88E-02	1.09E-01	1.18E-02	2.69E-02	0.00E+00	6.98E-08	1.12E-08	0.00E+00	0.00E+00	2.39E+00	1.85E-01	0.00E+00	0.00E+00

Ogata-Banks Solution, High V High C: Post-closure Loading to Dipeta, Scenario 1 (kg/yr)			Ogata-Banks Solution, Low V Low C: Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)	Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
8.22E+01	0.0 0.00E+00		1.03E+02	0.0 0.00E+00	
5.81E+01	0.0 0.00E+00		7.26E+01	0.0 0.00E+00	
4.74E+01	0.0 0.00E+00		5.93E+01	0.0 0.00E+00	
4.10E+01	0.0 0.00E+00		5.13E+01	0.0 0.00E+00	
3.67E+01	0.0 0.00E+00		4.59E+01	0.0 0.00E+00	
2.59E+01	0.0 0.00E+00		3.24E+01	0.0 0.00E+00	
2.11E+01	0.0 0.00E+00		2.64E+01	0.0 0.00E+00	
1.82E+01	0.0 0.00E+00		2.29E+01	0.0 0.00E+00	
1.63E+01	0.0 0.00E+00		2.04E+01	0.0 0.00E+00	
1.48E+01	0.0 0.00E+00		1.86E+01	0.0 0.00E+00	
1.37E+01	0.0 0.00E+00		1.72E+01	0.0 0.00E+00	
1.28E+01	0.0 0.00E+00		1.61E+01	0.0 0.00E+00	
1.21E+01	0.0 0.00E+00		1.52E+01	0.0 0.00E+00	
1.09E+01	0.0 0.00E+00		1.37E+01	0.0 0.00E+00	
9.95E+00	0.0 0.00E+00		1.26E+01	0.0 0.00E+00	
9.23E+00	0.0 0.00E+00		1.17E+01	0.0 0.00E+00	
8.64E+00	0.0 0.00E+00		1.09E+01	0.0 0.00E+00	
8.14E+00	0.0 0.00E+00		1.03E+01	0.0 0.00E+00	
5.46E+00	0.0 0.00E+00		7.02E+00	0.0 0.00E+00	
4.26E+00	0.0 0.00E+00		5.57E+00	0.0 0.00E+00	
3.53E+00	0.0 0.00E+00		4.69E+00	0.0 0.00E+00	
3.02E+00	0.0 0.00E+00		4.08E+00	0.0 0.00E+00	
2.63E+00	0.0 0.00E+00		3.62E+00	0.0 0.00E+00	
2.32E+00	0.0 0.00E+00		3.26E+00	0.0 0.00E+00	
2.06E+00	0.0 0.00E+00		2.96E+00	0.0 0.00E+00	
1.84E+00	0.0 1.79E-01		2.71E+00	0.0 0.00E+00	
1.65E+00	0.0 3.81E-01		2.49E+00	0.0 0.00E+00	

* End of operational period: 16 years







DATA SHEET 13 - chromium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	2696		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation **16**
Years to Pit Flow-Through **50**

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	325	152
	1	197,232	92,041
Ore Stockpile East	0	690	129
	1	492,038	91,847
Ore Stockpile Southwest	0	N/A	1,527
	1	N/A	164,562
Tailings Facility	0	325	152
	1	197,232	92,041
ROM Ore Stockpiles	0	N/A	17,455
	1	N/A	213,947
Pit to Dipeta	0	4,043	6,290
	1	119,572	186,804
Pit to Mofia	0	N/A	24,114
	1	N/A	404,181

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	344.624841	118766.2811	325.164356
	b	146.39	214.30	Scenario 2	235.423585	55424.26452	151.743366
	c	-53921	-53921				
Full Contribution	a	0.03	0.06	Scenario 1	8487.57	72,038,880	197,232
	b	-146.39	-214.30	Scenario 2	5798.12	33,618,144	92,041
	c	-862736	-862736				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	501.927351	251,931	690
	b	101.01	233.79	Scenario 2	216.857401	47,027	129
	c	-53921	-53921				
Full Contribution	a	0.01	0.07	Scenario 1	13405.85	179,716,893	492,038
	b	-101.01	-233.79	Scenario 2	5791.99	33,547,153	91,847
	c	-943617.5	-943617.5				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	233.72	Scenario 2	746.705339	557,569	1,527
	c	-202203.75	-202203.75				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-233.72	Scenario 2	7752.83058	60,106,382	164,562
	c	-1172781.75	-1172781.75				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	344.6248	118,766	325
	b	146.39	214.30	Scenario 2	235.4236	55,424	152
	c	-53921	-53921				
Full Contribu	a	0.03	0.06	Scenario 1	8487.572	72,038,880	197,232
	b	-146.39	-214.30	Scenario 2	5798.116	33,618,144	92,041
	c	-862736	-862736				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	301.72	Scenario 2	2524.94	6,375,324	17,455
	c	-1078420	-1078420				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-301.72	Scenario 2	8839.917	78,144,124	213,947
	c	-1213223	-1213222.5				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	1207.734	1,458,622	4,043
	b	434.00	347.20	Scenario 2	1509.668	2,279,097	6,290
	c	-674012.5	-674012.5				
Full Contribu	a	0.10	0.07	Scenario 1	6607.23	43,655,503	119,572
	b	-434.00	-347.20	Scenario 2	8259.04	68,211,724	186,804
	c	-1617630	-1617630				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	332.86	Scenario 2	2964.668	8,789,254	24,114
	c	-1348025	-1348025				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-434.00	-332.86	Scenario 2	12149.43	147,608,738	404,181
	c	-2022037.5	-2022037.5				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Scenario 1

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	1.26E-04	0.00E+00	0.00E+00	1.26E-04	0.00E+00	0.00E+00	0.00E+00
400	3.80E-04	0.00E+00	0.00E+00	3.80E-04	0.00E+00	0.00E+00	0.00E+00
450	6.34E-04	0.00E+00	0.00E+00	6.34E-04	0.00E+00	0.00E+00	0.00E+00
500	8.88E-04	0.00E+00	0.00E+00	8.88E-04	0.00E+00	0.00E+00	0.00E+00
600	1.40E-03	0.00E+00	0.00E+00	1.40E-03	0.00E+00	0.00E+00	0.00E+00
700	1.90E-03	2.09E-05	0.00E+00	1.90E-03	0.00E+00	0.00E+00	0.00E+00
800	2.41E-03	2.24E-04	0.00E+00	2.41E-03	0.00E+00	0.00E+00	0.00E+00
900	2.92E-03	4.28E-04	0.00E+00	2.92E-03	0.00E+00	0.00E+00	0.00E+00
1,000	3.43E-03	6.31E-04	0.00E+00	3.43E-03	0.00E+00	0.00E+00	0.00E+00
2,000	8.51E-03	2.67E-03	0.00E+00	8.51E-03	0.00E+00	0.00E+00	0.00E+00
3,000	1.36E-02	4.70E-03	0.00E+00	1.36E-02	0.00E+00	0.00E+00	0.00E+00
4,000	1.87E-02	6.74E-03	0.00E+00	1.87E-02	0.00E+00	0.00E+00	0.00E+00
5,000	2.37E-02	8.77E-03	0.00E+00	2.37E-02	0.00E+00	7.85E-03	0.00E+00
6,000	2.88E-02	1.08E-02	0.00E+00	2.88E-02	0.00E+00	1.65E-02	0.00E+00
7,000	3.39E-02	1.28E-02	0.00E+00	3.39E-02	0.00E+00	2.52E-02	0.00E+00
8,000	3.90E-02	1.49E-02	0.00E+00	3.90E-02	0.00E+00	3.38E-02	0.00E+00
9,000	4.41E-02	1.69E-02	0.00E+00	4.41E-02	0.00E+00	4.25E-02	0.00E+00
10,000	4.91E-02	1.89E-02	0.00E+00	4.91E-02	0.00E+00	5.11E-02	0.00E+00

Scenario 2

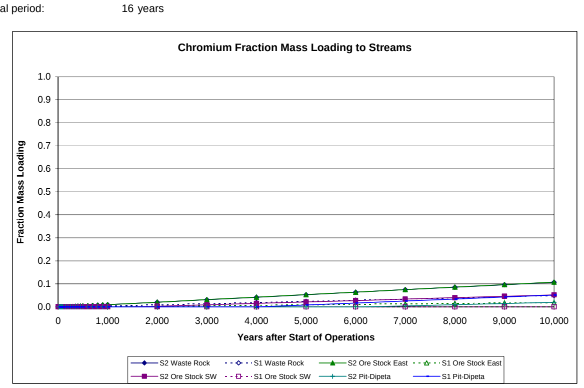
Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	2.32E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	5.25E-04	7.77E-04	0.00E+00	5.25E-04	0.00E+00	0.00E+00	0.00E+00
250	1.07E-03	1.32E-03	0.00E+00	1.07E-03	0.00E+00	0.00E+00	0.00E+00
300	1.61E-03	1.87E-03	0.00E+00	1.61E-03	0.00E+00	0.00E+00	0.00E+00
350	2.16E-03	2.41E-03	0.00E+00	2.16E-03	0.00E+00	0.00E+00	0.00E+00
400	2.70E-03	2.96E-03	0.00E+00	2.70E-03	0.00E+00	0.00E+00	0.00E+00
450	3.25E-03	3.50E-03	0.00E+00	3.25E-03	0.00E+00	0.00E+00	0.00E+00
500	3.79E-03	4.05E-03	0.00E+00	3.79E-03	0.00E+00	0.00E+00	0.00E+00
600	4.88E-03	5.14E-03	0.00E+00	4.88E-03	0.00E+00	0.00E+00	0.00E+00
700	5.97E-03	6.23E-03	0.00E+00	5.97E-03	0.00E+00	0.00E+00	0.00E+00
800	7.05E-03	7.32E-03	0.00E+00	7.05E-03	0.00E+00	0.00E+00	0.00E+00
900	8.14E-03	8.41E-03	0.00E+00	8.14E-03	0.00E+00	0.00E+00	0.00E+00
1,000	9.23E-03	9.50E-03	0.00E+00	9.23E-03	0.00E+00	0.00E+00	0.00E+00
2,000	2.01E-02	2.04E-02	2.90E-03	2.01E-02	0.00E+00	0.00E+00	0.00E+00
3,000	3.10E-02	3.13E-02	9.04E-03	3.10E-02	0.00E+00	0.00E+00	0.00E+00
4,000	4.19E-02	4.22E-02	1.52E-02	4.19E-02	0.00E+00	0.00E+00	0.00E+00
5,000	5.28E-02	5.31E-02	2.13E-02	5.28E-02	0.00E+00	0.00E+00	0.00E+00
6,000	6.36E-02	6.40E-02	2.74E-02	6.36E-02	0.00E+00	0.00E+00	0.00E+00
7,000	7.45E-02	7.49E-02	3.36E-02	7.45E-02	0.00E+00	3.66E-03	0.00E+00
8,000	8.54E-02	8.58E-02	3.97E-02	8.54E-02	0.00E+00	9.20E-03	0.00E+00
9,000	9.63E-02	9.67E-02	4.58E-02	9.63E-02	0.00E+00	1.47E-02	0.00E+00
10,000	1.07E-01	1.08E-01	5.20E-02	1.07E-01	0.00E+00	2.03E-02	0.00E+00

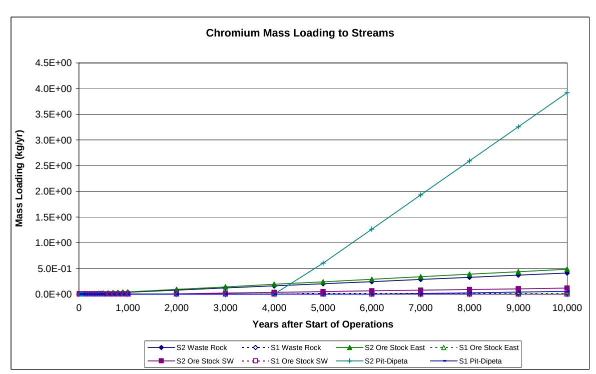
Loading Calculations to Kasana (kg/year)

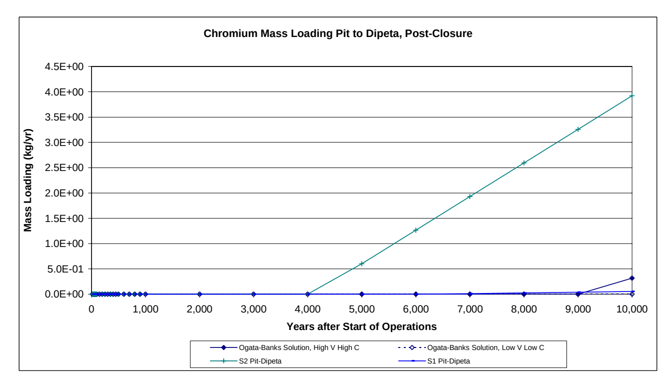
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	1.05E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	2.01E-03	0.00E+00	3.50E-03	0.00E+00	0.00E+00	0.00E+00	4.73E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	4.09E-03	0.00E+00	5.96E-03	0.00E+00	0.00E+00	0.00E+00	9.63E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	6.17E-03	0.00E+00	8.42E-03	0.00E+00	0.00E+00	0.00E+00	1.45E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	8.25E-03	4.16E-05	1.09E-02	0.00E+00	0.00E+00	0.00E+00	1.94E-08	7.08E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	1.03E-02	1.25E-04	1.33E-02	0.00E+00	0.00E+00	0.00E+00	2.43E-08	2.13E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	1.24E-02	2.09E-04	1.58E-02	0.00E+00	0.00E+00	0.00E+00	2.92E-08	3.56E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	1.45E-02	2.93E-04	1.83E-02	0.00E+00	0.00E+00	0.00E+00	3.41E-08	4.98E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	1.87E-02	4.61E-04	2.32E-02	0.00E+00	0.00E+00	0.00E+00	4.39E-08	7.83E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	2.28E-02	6.28E-04	2.81E-02	9.35E-06	0.00E+00	0.00E+00	5.37E-08	1.07E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	2.70E-02	7.96E-04	3.30E-02	1.01E-04	0.00E+00	0.00E+00	6.35E-08	1.35E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	3.11E-02	9.64E-04	3.79E-02	1.92E-04	0.00E+00	0.00E+00	7.33E-08	1.64E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	3.53E-02	1.13E-03	4.29E-02	2.83E-04	0.00E+00	0.00E+00	8.31E-08	1.92E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	7.69E-02	2.81E-03	9.20E-02	1.20E-03	6.55E-03	0.00E+00	1.81E-07	4.77E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	1.19E-01	4.48E-03	1.41E-01	2.11E-03	2.04E-02	0.00E+00	2.79E-07	7.62E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	1.60E-01	6.16E-03	1.90E-01	3.02E-03	3.42E-02	0.00E+00	3.77E-07	1.05E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	2.02E-01	7.84E-03	2.40E-01	3.93E-03	4.81E-02	0.00E+00	4.75E-07	1.33E-08	0.00E+00	0.00E+00	6.02E-01	0.00E+00	0.00E+00	0.00E+00
6,000	2.43E-01	9.51E-03	2.89E-01	4.85E-03	6.19E-02	0.00E+00	5.73E-07	1.62E-08	0.00E+00	0.00E+00	1.27E+00	0.00E+00	0.00E+00	0.00E+00
7,000	2.85E-01	1.12E-02	3.38E-01	5.76E-03	7.57E-02	0.00E+00	6.71E-07	1.90E-08	0.00E+00	0.00E+00	1.93E+00	9.88E-03	0.00E+00	0.00E+00
8,000	3.27E-01	1.29E-02	3.87E-01	6.67E-03	8.96E-02	0.00E+00	7.69E-07	2.19E-08	0.00E+00	0.00E+00	2.59E+00	2.49E-02	0.00E+00	0.00E+00
9,000	3.68E-01	1.45E-02	4.36E-01	7.58E-03	1.03E-01	0.00E+00	8.67E-07	2.47E-08	0.00E+00	0.00E+00	3.26E+00	3.98E-02	0.00E+00	0.00E+00
10,000	4.10E-01	1.62E-02	4.86E-01	8.49E-03	1.17E-01	0.00E+00	9.65E-07	2.76E-08	0.00E+00	0.00E+00	3.92E+00	5.48E-02	0.00E+00	0.00E+00

Time from Start of Operations (Years)*	Ogata-Banks Solution, High V High C – Post-closure Loading to Dipeta, Scenario 1 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)	Ogata-Banks Solution, Low V Low C – Post-closure Loading to Dipeta, Scenario 2 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)
0						
10						
16						
20	N/A	N/A	0	N/A	N/A	0
30	N/A	N/A	0	N/A	N/A	0
40	N/A	N/A	0	N/A	N/A	0
50	N/A	N/A	0	N/A	N/A	0
60	8.74E+01	0.0	0.00E+00	1.09E+02	0.0	0.00E+00
70	6.18E+01	0.0	0.00E+00	7.72E+01	0.0	0.00E+00
80	5.04E+01	0.0	0.00E+00	6.30E+01	0.0	0.00E+00
90	4.36E+01	0.0	0.00E+00	5.46E+01	0.0	0.00E+00
100	3.90E+01	0.0	0.00E+00	4.88E+01	0.0	0.00E+00
150	2.75E+01	0.0	0.00E+00	3.45E+01	0.0	0.00E+00
200	2.25E+01	0.0	0.00E+00	2.81E+01	0.0	0.00E+00
250	1.94E+01	0.0	0.00E+00	2.43E+01	0.0	0.00E+00
300	1.73E+01	0.0	0.00E+00	2.17E+01	0.0	0.00E+00
350	1.58E+01	0.0	0.00E+00	1.98E+01	0.0	0.00E+00
400	1.46E+01	0.0	0.00E+00	1.83E+01	0.0	0.00E+00
450	1.36E+01	0.0	0.00E+00	1.71E+01	0.0	0.00E+00
500	1.28E+01	0.0	0.00E+00	1.61E+01	0.0	0.00E+00
600	1.16E+01	0.0	0.00E+00	1.46E+01	0.0	0.00E+00
700	1.06E+01	0.0	0.00E+00	1.34E+01	0.0	0.00E+00
800	9.84E+00	0.0	0.00E+00	1.24E+01	0.0	0.00E+00
900	9.22E+00	0.0	0.00E+00	1.16E+01	0.0	0.00E+00
1,000	8.69E+00	0.0	0.00E+00	1.10E+01	0.0	0.00E+00
2,000	5.86E+00	0.0	0.00E+00	7.50E+00	0.0	0.00E+00
3,000	4.60E+00	0.0	0.00E+00	5.97E+00	0.0	0.00E+00
4,000	3.83E+00	0.0	0.00E+00	5.04E+00	0.0	0.00E+00
5,000	3.29E+00	0.0	0.00E+00	4.40E+00	0.0	0.00E+00
6,000	2.88E+00	0.0	0.00E+00	3.92E+00	0.0	0.00E+00
7,000	2.56E+00	0.0	0.00E+00	3.54E+00	0.0	0.00E+00
8,000	2.29E+00	0.0	0.00E+00	3.23E+00	0.0	0.00E+00
9,000	2.07E+00	0.0	0.00E+00	2.97E+00	0.0	0.00E+00
10,000	1.87E+00	0.0	3.16E-01	2.74E+00	0.0	0.00E+00

* End of operational period: 16 years







DATA SHEET 14 - nickel

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	2796		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	337	157
	1	204,560	95,461
Ore Stockpile East	0	715	134
	1	510,319	95,260
Ore Stockpile Southwest	0	N/A	1,583
	1	N/A	170,677
Tailings Facility	0	337	157
	1	204,560	95,461
ROM Ore Stockpiles	0	N/A	18,103
	1	N/A	221,896
Pit to Dipeta	0	4,192	6,522
	1	124,013	193,742
Pit to Mofia	0	N/A	25,008
	1	N/A	419,196

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	350.968611	123178.9657	337.245628
	b	149.09	218.24	Scenario 2	239.757205	57483.51735	157.381293
	c	-55924.4	-55924.4				
Full Contribution	a	0.03	0.06	Scenario 1	8643.81	74,715,439	204,560
	b	-149.09	-218.24	Scenario 2	5904.85	34,867,205	95,461
	c	-894790.4	-894790.4				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	511.166707	261,291	715
	b	102.87	238.10	Scenario 2	220.849259	48,774	134
	c	-55924.4	-55924.4				
Full Contribution	a	0.01	0.07	Scenario 1	13652.62	186,394,158	510,319
	b	-102.87	-238.10	Scenario 2	5898.61	34,793,576	95,260
	c	-978677	-978677				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	238.02	Scenario 2	760.450508	578,285	1,583
	c	-209716.5	-209716.5				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-238.02	Scenario 2	7895.54278	62,339,596	170,677
	c	-1216355.7	-1216355.7				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	350.9686	123,179	337
	b	149.09	218.24	Scenario 2	239.7572	57,484	157
	c	-55924.4	-55924.4				
Full Contribution	a	0.03	0.06	Scenario 1	8643.809	74,715,439	204,560
	b	-149.09	-218.24	Scenario 2	5904.846	34,867,205	95,461
	c	-894790.4	-894790.4				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	307.28	Scenario 2	2571.419	6,612,195	18,103
	c	-1118488	-1118488				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-307.28	Scenario 2	9002.64	81,047,518	221,896
	c	-1258299	-1258299				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	1229.966	1,512,816	4,192
	b	441.99	353.59	Scenario 2	1537.457	2,363,775	6,522
	c	-699055	-699055				
Full Contribution	a	0.10	0.07	Scenario 1	6728.86	45,277,495	124,013
	b	-441.99	-353.59	Scenario 2	8411.07	70,746,086	193,742
	c	-1677732	-1677732				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	338.99	Scenario 2	3019.24	9,115,813	25,008
	c	-1398110	-1398110				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-441.99	-338.99	Scenario 2	12373.08	153,093,045	419,196
	c	-2097165	-2097165				

Scenario 1

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	6.25E-05	0.00E+00	0.00E+00	6.25E-05	0.00E+00	0.00E+00	0.00E+00
400	3.07E-04	0.00E+00	0.00E+00	3.07E-04	0.00E+00	0.00E+00	0.00E+00
450	5.52E-04	0.00E+00	0.00E+00	5.52E-04	0.00E+00	0.00E+00	0.00E+00
500	7.97E-04	0.00E+00	0.00E+00	7.97E-04	0.00E+00	0.00E+00	0.00E+00
600	1.29E-03	0.00E+00	0.00E+00	1.29E-03	0.00E+00	0.00E+00	0.00E+00
700	1.78E-03	0.00E+00	0.00E+00	1.78E-03	0.00E+00	0.00E+00	0.00E+00
800	2.27E-03	1.66E-04	0.00E+00	2.27E-03	0.00E+00	0.00E+00	0.00E+00
900	2.76E-03	3.62E-04	0.00E+00	2.76E-03	0.00E+00	0.00E+00	0.00E+00
1,000	3.25E-03	5.59E-04	0.00E+00	3.25E-03	0.00E+00	0.00E+00	0.00E+00
2,000	8.14E-03	2.52E-03	0.00E+00	8.14E-03	0.00E+00	0.00E+00	0.00E+00
3,000	1.30E-02	4.48E-03	0.00E+00	1.30E-02	0.00E+00	0.00E+00	0.00E+00
4,000	1.79E-02	6.45E-03	0.00E+00	1.79E-02	0.00E+00	0.00E+00	0.00E+00
5,000	2.28E-02	8.41E-03	0.00E+00	2.28E-02	0.00E+00	6.33E-03	0.00E+00
6,000	2.77E-02	1.04E-02	0.00E+00	2.77E-02	0.00E+00	1.47E-02	0.00E+00
7,000	3.26E-02	1.23E-02	0.00E+00	3.26E-02	0.00E+00	2.30E-02	0.00E+00
8,000	3.75E-02	1.43E-02	0.00E+00	3.75E-02	0.00E+00	3.14E-02	0.00E+00
9,000	4.24E-02	1.63E-02	0.00E+00	4.24E-02	0.00E+00	3.97E-02	0.00E+00
10,000	4.73E-02	1.82E-02	0.00E+00	4.73E-02	0.00E+00	4.81E-02	0.00E+00

Scenario 2

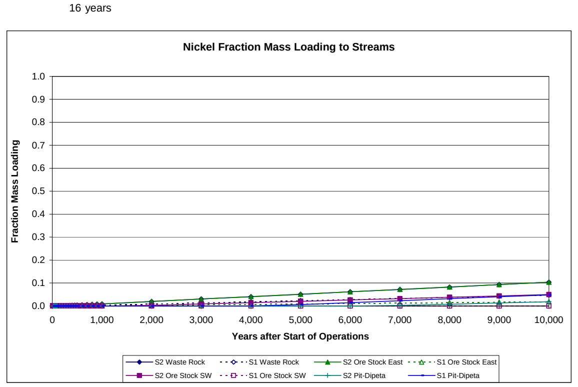
Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	1.73E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	4.47E-04	6.99E-04	0.00E+00	4.47E-04	0.00E+00	0.00E+00	0.00E+00
250	9.72E-04	1.22E-03	0.00E+00	9.72E-04	0.00E+00	0.00E+00	0.00E+00
300	1.50E-03	1.75E-03	0.00E+00	1.50E-03	0.00E+00	0.00E+00	0.00E+00
350	2.02E-03	2.28E-03	0.00E+00	2.02E-03	0.00E+00	0.00E+00	0.00E+00
400	2.55E-03	2.80E-03	0.00E+00	2.55E-03	0.00E+00	0.00E+00	0.00E+00
450	3.07E-03	3.33E-03	0.00E+00	3.07E-03	0.00E+00	0.00E+00	0.00E+00
500	3.60E-03	3.85E-03	0.00E+00	3.60E-03	0.00E+00	0.00E+00	0.00E+00
600	4.64E-03	4.90E-03	0.00E+00	4.64E-03	0.00E+00	0.00E+00	0.00E+00
700	5.69E-03	5.95E-03	0.00E+00	5.69E-03	0.00E+00	0.00E+00	0.00E+00
800	6.74E-03	7.01E-03	0.00E+00	6.74E-03	0.00E+00	0.00E+00	0.00E+00
900	7.79E-03	8.06E-03	0.00E+00	7.79E-03	0.00E+00	0.00E+00	0.00E+00
1,000	8.84E-03	9.11E-03	0.00E+00	8.84E-03	0.00E+00	0.00E+00	0.00E+00
2,000	1.93E-02	1.96E-02	2.46E-03	1.93E-02	0.00E+00	0.00E+00	0.00E+00
3,000	2.98E-02	3.01E-02	8.38E-03	2.98E-02	0.00E+00	0.00E+00	0.00E+00
4,000	4.03E-02	4.06E-02	1.43E-02	4.03E-02	0.00E+00	0.00E+00	0.00E+00
5,000	5.08E-02	5.12E-02	2.02E-02	5.08E-02	0.00E+00	0.00E+00	0.00E+00
6,000	6.13E-02	6.17E-02	2.61E-02	6.13E-02	0.00E+00	0.00E+00	0.00E+00
7,000	7.18E-02	7.22E-02	3.20E-02	7.18E-02	0.00E+00	2.29E-03	0.00E+00
8,000	8.23E-02	8.27E-02	3.79E-02	8.23E-02	0.00E+00	7.63E-03	0.00E+00
9,000	9.28E-02	9.32E-02	4.39E-02	9.28E-02	0.00E+00	1.30E-02	0.00E+00
10,000	1.03E-01	1.04E-01	4.98E-02	1.03E-01	0.00E+00	1.83E-02	0.00E+00

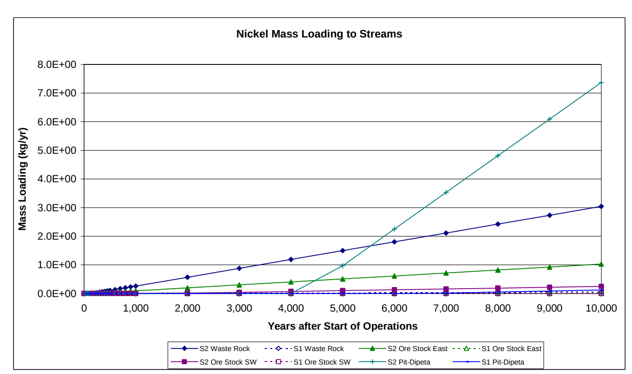
Loading Calculations to Kasana (kg/year)

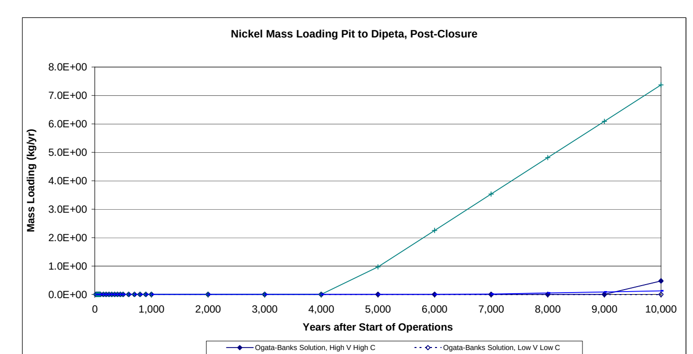
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	1.72E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	1.32E-02	0.00E+00	6.94E-03	0.00E+00	0.00E+00	0.00E+00	1.18E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	2.86E-02	0.00E+00	1.22E-02	0.00E+00	0.00E+00	0.00E+00	2.57E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	4.41E-02	0.00E+00	1.74E-02	0.00E+00	0.00E+00	0.00E+00	3.96E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	5.95E-02	6.06E-05	2.26E-02	0.00E+00	0.00E+00	0.00E+00	5.35E-09	1.25E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	7.50E-02	2.98E-04	2.78E-02	0.00E+00	0.00E+00	0.00E+00	6.74E-09	6.15E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	9.04E-02	5.36E-04	3.30E-02	0.00E+00	0.00E+00	0.00E+00	8.13E-09	1.10E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	1.06E-01	7.74E-04	3.83E-02	0.00E+00	0.00E+00	0.00E+00	9.52E-09	1.59E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	1.37E-01	1.25E-03	4.87E-02	0.00E+00	0.00E+00	0.00E+00	1.23E-08	2.57E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	1.68E-01	1.72E-03	5.91E-02	0.00E+00	0.00E+00	0.00E+00	1.51E-08	3.55E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	1.99E-01	2.20E-03	6.96E-02	4.19E-05	0.00E+00	0.00E+00	1.79E-08	4.53E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	2.29E-01	2.68E-03	8.00E-02	9.14E-05	0.00E+00	0.00E+00	2.06E-08	5.51E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	2.60E-01	3.15E-03	9.05E-02	1.41E-04	0.00E+00	0.00E+00	2.34E-08	6.49E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	5.69E-01	7.91E-03	1.95E-01	6.36E-04	1.22E-02	0.00E+00	5.12E-08	1.63E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	8.78E-01	1.27E-02	2.99E-01	1.13E-03	4.16E-02	0.00E+00	7.90E-08	2.61E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	1.19E+00	1.74E-02	4.04E-01	1.63E-03	7.10E-02	0.00E+00	1.07E-07	3.59E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	1.50E+00	2.22E-02	5.08E-01	2.12E-03	1.00E-01	0.00E+00	1.35E-07	4.57E-09	0.00E+00	0.00E+00	9.71E-01	0.00E+00	0.00E+00	0.00E+00
6,000	1.81E+00	2.69E-02	6.13E-01	2.61E-03	1.30E-01	0.00E+00	1.62E-07	5.55E-09	0.00E+00	0.00E+00	2.25E+00	0.00E+00	0.00E+00	0.00E+00
7,000	2.11E+00	3.17E-02	7.17E-01	3.11E-03	1.59E-01	0.00E+00	1.90E-07	6.53E-09	0.00E+00	0.00E+00	3.53E+00	1.55E-02	0.00E+00	0.00E+00
8,000	2.42E+00	3.64E-02	8.21E-01	3.60E-03	1.88E-01	0.00E+00	2.18E-07	7.51E-09	0.00E+00	0.00E+00	4.81E+00	5.16E-02	0.00E+00	0.00E+00
9,000	2.73E+00	4.12E-02	9.26E-01	4.10E-03	2.18E-01	0.00E+00	2.46E-07	8.49E-09	0.00E+00	0.00E+00	6.09E+00	8.76E-02	0.00E+00	0.00E+00
10,000	3.04E+00	4.59E-02	1.03E+00	4.59E-03	2.47E-01	0.00E+00	2.74E-07	9.47E-09	0.00E+00	0.00E+00	7.37E+00	1.24E-01	0.00E+00	0.00E+00

Time from Start of Operations (Years)*	Ogata-Banks Solution, High V High C — Post-closure Loading to Dipeta, Scenario 1 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)	Ogata-Banks Solution, Low V Low C — Post-closure Loading to Dipeta, Scenario 2 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)
0						
10						
16						
20	N/A	N/A	0	N/A	N/A	0
30	N/A	N/A	0	N/A	N/A	0
40	N/A	N/A	0	N/A	N/A	0
50	N/A	N/A	0	N/A	N/A	0
60	8.90E+01	0.0	0.00E+00	1.11E+02	0.0	0.00E+00
70	6.29E+01	0.0	0.00E+00	7.86E+01	0.0	0.00E+00
80	5.13E+01	0.0	0.00E+00	6.42E+01	0.0	0.00E+00
90	4.44E+01	0.0	0.00E+00	5.56E+01	0.0	0.00E+00
100	3.97E+01	0.0	0.00E+00	4.97E+01	0.0	0.00E+00
150	2.81E+01	0.0	0.00E+00	3.51E+01	0.0	0.00E+00
200	2.29E+01	0.0	0.00E+00	2.86E+01	0.0	0.00E+00
250	1.98E+01	0.0	0.00E+00	2.48E+01	0.0	0.00E+00
300	1.77E+01	0.0	0.00E+00	2.21E+01	0.0	0.00E+00
350	1.61E+01	0.0	0.00E+00	2.02E+01	0.0	0.00E+00
400	1.49E+01	0.0	0.00E+00	1.87E+01	0.0	0.00E+00
450	1.39E+01	0.0	0.00E+00	1.74E+01	0.0	0.00E+00
500	1.31E+01	0.0	0.00E+00	1.64E+01	0.0	0.00E+00
600	1.18E+01	0.0	0.00E+00	1.48E+01	0.0	0.00E+00
700	1.08E+01	0.0	0.00E+00	1.36E+01	0.0	0.00E+00
800	1.00E+01	0.0	0.00E+00	1.27E+01	0.0	0.00E+00
900	9.40E+00	0.0	0.00E+00	1.19E+01	0.0	0.00E+00
1,000	8.86E+00	0.0	0.00E+00	1.12E+01	0.0	0.00E+00
2,000	5.98E+00	0.0	0.00E+00	7.65E+00	0.0	0.00E+00
3,000	4.70E+00	0.0	0.00E+00	6.09E+00	0.0	0.00E+00
4,000	3.92E+00	0.0	0.00E+00	5.15E+00	0.0	0.00E+00
5,000	3.38E+00	0.0	0.00E+00	4.50E+00	0.0	0.00E+00
6,000	2.96E+00	0.0	0.00E+00	4.01E+00	0.0	0.00E+00
7,000	2.64E+00	0.0	0.00E+00	3.63E+00	0.0	0.00E+00
8,000	2.36E+00	0.0	0.00E+00	3.31E+00	0.0	0.00E+00
9,000	2.13E+00	0.0	0.00E+00	3.05E+00	0.0	0.00E+00
10,000	1.94E+00	0.0	4.76E-01	2.82E+00	0.0	0.00E+00

* End of operational period: 16 years







DATA SHEET 15 - copper

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	4399		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	531	248
	1	321,808	150,177
Ore Stockpile East	0	1,125	210
	1	802,821	149,860
Ore Stockpile Southwest	0	N/A	2,491
	1	N/A	268,504
Tailings Facility	0	531	248
	1	321,808	150,177
ROM Ore Stockpiles	0	N/A	28,479
	1	N/A	349,081
Pit to Dipeta	0	6,566	10,231
	1	195,065	304,762
Pit to Mofia	0	N/A	39,313
	1	N/A	659,439

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	440.206678	193781.9197	530.545981
	b	186.99	273.73	Scenario 2	300.718411	90431.56254	247.588125
	c	-87978.8	-87978.8				
Full Contribution	a	0.03	0.06	Scenario 1	10841.60	117,540,369	321,808
	b	-186.99	-273.73	Scenario 2	7406.23	54,852,172	150,177
	c	-1407660.8	-1407660.8				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	641.137103	411,057	1,125
	b	129.03	298.64	Scenario 2	277.002888	76,731	210
	c	-87978.8	-87978.8				
Full Contribution	a	0.01	0.07	Scenario 1	17123.97	293,230,404	802,821
	b	-129.03	-298.64	Scenario 2	7398.40	54,736,342	149,860
	c	-1539629	-1539629				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	298.54	Scenario 2	953.804363	909,743	2,491
	c	-329920.5	-329920.5				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-298.54	Scenario 2	9903.08123	98,071,018	268,504
	c	-1913538.9	-1913538.9				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	440.2067	193,782	531
	b	186.99	273.73	Scenario 2	300.7184	90,432	248
	c	-87978.8	-87978.8				
Full Contribu	a	0.03	0.06	Scenario 1	10841.6	117,540,369	321,808
	b	-186.99	-273.73	Scenario 2	7406.225	54,852,172	150,177
	c	-1407661	-1407660.8				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	385.41	Scenario 2	3225.234	10,402,132	28,479
	c	-1759576	-1759576				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-385.41	Scenario 2	11291.67	127,501,831	349,081
	c	-1979523	-1979523				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	1542.7	2,379,922	6,566
	b	554.37	443.49	Scenario 2	1928.375	3,718,629	10,231
	c	-1099735	-1099735				
Full Contribu	a	0.10	0.07	Scenario 1	8439.75	71,229,369	195,065
	b	-554.37	-443.49	Scenario 2	10549.69	111,295,889	304,762
	c	-2639364	-2639364				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	425.18	Scenario 2	3786.919	14,340,758	39,313
	c	-2199470	-2199470				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-554.37	-425.18	Scenario 2	15519.08	240,841,965	659,439
	c	-3299205	-3299205				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

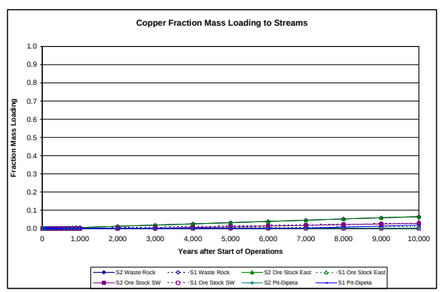
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-05	2.67E-04	0.00E+00	1.61E-05	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.50E-04	6.01E-04	0.00E+00	3.50E-04	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.83E-04	9.35E-04	0.00E+00	6.83E-04	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-03	1.27E-03	0.00E+00	1.02E-03	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E-03	1.60E-03	0.00E+00	1.35E-03	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.68E-03	1.94E-03	0.00E+00	1.68E-03	0.00E+00	0.00E+00	0.00E+00
600	2.16E-04	0.00E+00	0.00E+00	2.16E-04	0.00E+00	0.00E+00	0.00E+00	2.35E-03	2.61E-03	0.00E+00	2.35E-03	0.00E+00	0.00E+00	0.00E+00
700	5.27E-04	0.00E+00	0.00E+00	5.27E-04	0.00E+00	0.00E+00	0.00E+00	3.02E-03	3.27E-03	0.00E+00	3.02E-03	0.00E+00	0.00E+00	0.00E+00
800	8.39E-04	0.00E+00	0.00E+00	8.39E-04	0.00E+00	0.00E+00	0.00E+00	3.68E-03	3.94E-03	0.00E+00	3.68E-03	0.00E+00	0.00E+00	0.00E+00
900	1.15E-03	0.00E+00	0.00E+00	1.15E-03	0.00E+00	0.00E+00	0.00E+00	4.35E-03	4.61E-03	0.00E+00	4.35E-03	0.00E+00	0.00E+00	0.00E+00
1,000	1.46E-03	0.00E+00	0.00E+00	1.46E-03	0.00E+00	0.00E+00	0.00E+00	5.02E-03	5.28E-03	0.00E+00	5.02E-03	0.00E+00	0.00E+00	0.00E+00
2,000	4.57E-03	1.09E-03	0.00E+00	4.57E-03	0.00E+00	0.00E+00	0.00E+00	1.17E-02	1.20E-02	0.00E+00	1.17E-02	0.00E+00	0.00E+00	0.00E+00
3,000	7.69E-03	2.34E-03	0.00E+00	7.69E-03	0.00E+00	0.00E+00	0.00E+00	1.84E-02	1.86E-02	1.91E-03	1.84E-02	0.00E+00	0.00E+00	0.00E+00
4,000	1.08E-02	3.59E-03	0.00E+00	1.08E-02	0.00E+00	0.00E+00	0.00E+00	2.50E-02	2.53E-02	5.67E-03	2.50E-02	0.00E+00	0.00E+00	0.00E+00
5,000	1.39E-02	4.83E-03	0.00E+00	1.39E-02	0.00E+00	0.00E+00	0.00E+00	3.17E-02	3.20E-02	9.43E-03	3.17E-02	0.00E+00	0.00E+00	0.00E+00
6,000	1.70E-02	6.08E-03	0.00E+00	1.70E-02	0.00E+00	0.00E+00	0.00E+00	3.84E-02	3.87E-02	1.32E-02	3.84E-02	0.00E+00	0.00E+00	0.00E+00
7,000	2.01E-02	7.33E-03	0.00E+00	2.01E-02	0.00E+00	2.04E-03	0.00E+00	4.50E-02	4.54E-02	1.70E-02	4.50E-02	0.00E+00	0.00E+00	0.00E+00
8,000	2.32E-02	8.58E-03	0.00E+00	2.32E-02	0.00E+00	7.34E-03	0.00E+00	5.17E-02	5.21E-02	2.07E-02	5.17E-02	0.00E+00	0.00E+00	0.00E+00
9,000	2.64E-02	9.82E-03	0.00E+00	2.64E-02	0.00E+00	1.26E-02	0.00E+00	5.84E-02	5.87E-02	2.45E-02	5.84E-02	0.00E+00	0.00E+00	0.00E+00
10,000	2.95E-02	1.11E-02	0.00E+00	2.95E-02	0.00E+00	1.80E-02	0.00E+00	6.50E-02	6.54E-02	2.82E-02	6.50E-02	0.00E+00	0.00E+00	0.00E+00

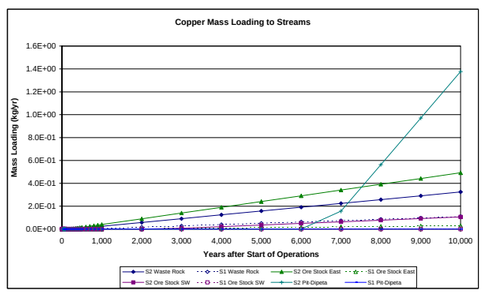
Loading Calculations to Kasana (kg/year)

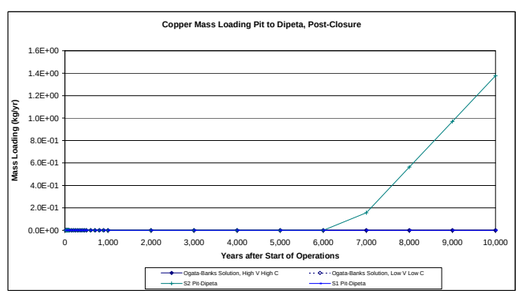
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	8.02E-05	0.00E+00	2.01E-03	0.00E+00	0.00E+00	0.00E+00	4.28E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	3.50E-04	0.00E+00	4.52E-03	0.00E+00	0.00E+00	0.00E+00	9.29E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	3.40E-03	0.00E+00	7.04E-03	0.00E+00	0.00E+00	0.00E+00	1.82E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	5.07E-03	0.00E+00	9.55E-03	0.00E+00	0.00E+00	0.00E+00	2.70E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	6.73E-03	0.00E+00	1.21E-02	0.00E+00	0.00E+00	0.00E+00	3.59E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	8.39E-03	0.00E+00	1.46E-02	0.00E+00	0.00E+00	0.00E+00	4.47E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	1.17E-02	7.98E-04	1.96E-02	0.00E+00	0.00E+00	0.00E+00	6.25E-08	4.54E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	1.50E-02	1.95E-03	2.46E-02	0.00E+00	0.00E+00	0.00E+00	8.02E-08	1.11E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	1.84E-02	3.10E-03	2.97E-02	0.00E+00	0.00E+00	0.00E+00	9.79E-08	1.76E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	2.17E-02	4.25E-03	3.47E-02	0.00E+00	0.00E+00	0.00E+00	1.16E-07	2.41E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	2.50E-02	5.40E-03	3.97E-02	0.00E+00	0.00E+00	0.00E+00	1.33E-07	3.07E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	5.82E-02	1.69E-02	9.00E-02	3.00E-03	0.00E+00	0.00E+00	3.11E-07	9.60E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	9.15E-02	2.84E-02	1.40E-01	6.42E-03	7.20E-03	0.00E+00	4.88E-07	1.61E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	1.25E-01	3.99E-02	1.91E-01	9.85E-03	2.13E-02	0.00E+00	6.65E-07	2.27E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	1.58E-01	5.14E-02	2.41E-01	1.33E-02	3.55E-02	0.00E+00	8.42E-07	2.92E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	1.91E-01	6.29E-02	2.91E-01	1.67E-02	4.96E-02	0.00E+00	1.02E-06	3.57E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	2.24E-01	7.44E-02	3.41E-01	2.01E-02	6.38E-02	0.00E+00	1.20E-06	4.23E-08	0.00E+00	0.00E+00	1.56E-01	0.00E+00	0.00E+00	0.00E+00
8,000	2.58E-01	8.59E-02	3.92E-01	2.36E-02	7.79E-02	0.00E+00	1.37E-06	4.88E-08	0.00E+00	0.00E+00	5.63E-01	0.00E+00	0.00E+00	0.00E+00
9,000	2.91E-01	9.74E-02	4.42E-01	2.70E-02	9.21E-02	0.00E+00	1.55E-06	5.53E-08	0.00E+00	0.00E+00	9.70E-01	0.00E+00	0.00E+00	0.00E+00
10,000	3.24E-01	1.09E-01	4.92E-01	3.04E-02	1.06E-01	0.00E+00	1.73E-06	6.19E-08	0.00E+00	0.00E+00	1.38E+00	0.00E+00	0.00E+00	0.00E+00

* End of operational period: 16 years

Ogata-Banks Solution, High V High C				Ogata-Banks Solution, Low V Low C			
Post-closure Loading to Dipeta, Scenario 1 (kg/yr)				Post-closure Loading to Dipeta, Scenario 2 (kg/yr)			
Time from Start of Operations (Years)*	Beta	erfc (Beta)	Mass Loading (kg/yr)	Time from Start of Operations (Years)*	Beta	erfc (Beta)	Mass Loading (kg/yr)
0				0			
10				10			
16				**16**			
20	N/A	N/A	0	20	N/A	N/A	0
30	N/A	N/A	0	30	N/A	N/A	0
40	N/A	N/A	0	40	N/A	N/A	0
50	N/A	N/A	0	50	N/A	N/A	0
60	1.12E+02	0.0	0.00E+00	60	1.40E+02	0.0	0.00E+00
70	7.89E+01	0.0	0.00E+00	70	9.87E+01	0.0	0.00E+00
80	6.44E+01	0.0	0.00E+00	80	8.05E+01	0.0	0.00E+00
90	5.58E+01	0.0	0.00E+00	90	6.97E+01	0.0	0.00E+00
100	4.99E+01	0.0	0.00E+00	100	6.24E+01	0.0	0.00E+00
150	3.52E+01	0.0	0.00E+00	150	4.41E+01	0.0	0.00E+00
200	2.87E+01	0.0	0.00E+00	200	3.60E+01	0.0	0.00E+00
250	2.49E+01	0.0	0.00E+00	250	3.11E+01	0.0	0.00E+00
300	2.22E+01	0.0	0.00E+00	300	2.78E+01	0.0	0.00E+00
350	2.03E+01	0.0	0.00E+00	350	2.54E+01	0.0	0.00E+00
400	1.87E+01	0.0	0.00E+00	400	2.35E+01	0.0	0.00E+00
450	1.75E+01	0.0	0.00E+00	450	2.20E+01	0.0	0.00E+00
500	1.65E+01	0.0	0.00E+00	500	2.07E+01	0.0	0.00E+00
600	1.49E+01	0.0	0.00E+00	600	1.87E+01	0.0	0.00E+00
700	1.37E+01	0.0	0.00E+00	700	1.72E+01	0.0	0.00E+00
800	1.27E+01	0.0	0.00E+00	800	1.60E+01	0.0	0.00E+00
900	1.19E+01	0.0	0.00E+00	900	1.50E+01	0.0	0.00E+00
1,000	1.12E+01	0.0	0.00E+00	1,000	1.41E+01	0.0	0.00E+00
2,000	7.68E+00	0.0	0.00E+00	2,000	9.74E+00	0.0	0.00E+00
3,000	6.12E+00	0.0	0.00E+00	3,000	7.82E+00	0.0	0.00E+00
4,000	5.17E+00	0.0	0.00E+00	4,000	6.67E+00	0.0	0.00E+00
5,000	4.52E+00	0.0	0.00E+00	5,000	5.87E+00	0.0	0.00E+00
6,000	4.03E+00	0.0	0.00E+00	6,000	5.28E+00	0.0	0.00E+00
7,000	3.64E+00	0.0	0.00E+00	7,000	4.82E+00	0.0	0.00E+00
8,000	3.33E+00	0.0	0.00E+00	8,000	4.44E+00	0.0	0.00E+00
9,000	3.06E+00	0.0	0.00E+00	9,000	4.13E+00	0.0	0.00E+00
10,000	2.83E+00	0.0	0.00E+00	10,000	3.86E+00	0.0	0.00E+00







DATA SHEET 16 - strontium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	4771		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	575	269
	1	349,026	162,879
Ore Stockpile East	0	1,221	228
	1	870,723	162,535
Ore Stockpile Southwest	0	N/A	2,701
	1	N/A	291,214
Tailings Facility	0	575	269
	1	349,026	162,879
ROM Ore Stockpiles	0	N/A	30,888
	1	N/A	378,606
Pit to Dipeta	0	7,117	11,092
	1	211,560	330,534
Pit to Mofia	0	N/A	42,634
	1	N/A	715,210

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	458.44508	210171.8912	575.419278
	b	194.74	285.07	Scenario 2	313.177611	98080.21588	268.528996
	c	-95420	-95420				
Full Contribution	a	0.03	0.06	Scenario 1	11290.79	127,481,871	349,026
	b	-194.74	-285.07	Scenario 2	7713.08	59,491,540	162,879
	c	-1526720	-1526720				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	667.700343	445,824	1,221
	b	134.37	311.01	Scenario 2	288.479519	83,220	228
	c	-95420	-95420				
Full Contribution	a	0.01	0.07	Scenario 1	17833.44	318,031,675	870,723
	b	-134.37	-311.01	Scenario 2	7704.93	59,365,913	162,535
	c	-1669850	-1669850				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	310.90	Scenario 2	993.321862	986,688	2,701
	c	-357825	-357825				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-310.90	Scenario 2	10313.3803	106,365,812	291,214
	c	-2075385	-2075385				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	458.4451	210,172	575
	b	194.74	285.07	Scenario 2	313.1776	98,080	269
	c	-95420	-95420				
Full Contribution	a	0.03	0.06	Scenario 1	11290.79	127,481,871	349,026
	b	-194.74	-285.07	Scenario 2	7713.076	59,491,540	162,879
	c	-1526720	-1526720				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	401.38	Scenario 2	3358.86	11,281,939	30,888
	c	-1908400	-1908400				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-401.38	Scenario 2	11759.5	138,285,868	378,606
	c	-2146950	-2146950				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	1606.616	2,581,215	7,117
	b	577.34	461.87	Scenario 2	2008.27	4,033,148	11,092
	c	-1192750	-1192750				
Full Contribution	a	0.10	0.07	Scenario 1	8789.42	77,253,911	211,560
	b	-577.34	-461.87	Scenario 2	10986.78	120,709,236	330,534
	c	-2862600	-2862600				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	442.80	Scenario 2	3943.817	15,553,691	42,634
	c	-2385500	-2385500				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-577.34	-442.80	Scenario 2	16162.06	261,212,250	715,210
	c	-3578250	-3578250				

Scenario 1

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	7.05E-05	0.00E+00	0.00E+00	7.05E-05	0.00E+00	0.00E+00	0.00E+00
700	3.58E-04	0.00E+00	0.00E+00	3.58E-04	0.00E+00	0.00E+00	0.00E+00
800	6.45E-04	0.00E+00	0.00E+00	6.45E-04	0.00E+00	0.00E+00	0.00E+00
900	9.31E-04	0.00E+00	0.00E+00	9.31E-04	0.00E+00	0.00E+00	0.00E+00
1,000	1.22E-03	0.00E+00	0.00E+00	1.22E-03	0.00E+00	0.00E+00	0.00E+00
2,000	4.09E-03	8.96E-04	0.00E+00	4.09E-03	0.00E+00	0.00E+00	0.00E+00
3,000	6.96E-03	2.05E-03	0.00E+00	6.96E-03	0.00E+00	0.00E+00	0.00E+00
4,000	9.83E-03	3.20E-03	0.00E+00	9.83E-03	0.00E+00	0.00E+00	0.00E+00
5,000	1.27E-02	4.35E-03	0.00E+00	1.27E-02	0.00E+00	0.00E+00	0.00E+00
6,000	1.56E-02	5.50E-03	0.00E+00	1.56E-02	0.00E+00	0.00E+00	0.00E+00
7,000	1.84E-02	6.65E-03	0.00E+00	1.84E-02	0.00E+00	0.00E+00	0.00E+00
8,000	2.13E-02	7.80E-03	0.00E+00	2.13E-02	0.00E+00	4.07E-03	0.00E+00
9,000	2.42E-02	8.95E-03	0.00E+00	2.42E-02	0.00E+00	8.97E-03	0.00E+00
10,000	2.70E-02	1.01E-02	0.00E+00	2.70E-02	0.00E+00	1.39E-02	0.00E+00

Scenario 2

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	1.36E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	1.94E-04	4.45E-04	0.00E+00	1.94E-04	0.00E+00	0.00E+00	0.00E+00
350	5.01E-04	7.53E-04	0.00E+00	5.01E-04	0.00E+00	0.00E+00	0.00E+00
400	8.09E-04	1.06E-03	0.00E+00	8.09E-04	0.00E+00	0.00E+00	0.00E+00
450	1.12E-03	1.37E-03	0.00E+00	1.12E-03	0.00E+00	0.00E+00	0.00E+00
500	1.42E-03	1.68E-03	0.00E+00	1.42E-03	0.00E+00	0.00E+00	0.00E+00
600	2.04E-03	2.29E-03	0.00E+00	2.04E-03	0.00E+00	0.00E+00	0.00E+00
700	2.65E-03	2.91E-03	0.00E+00	2.65E-03	0.00E+00	0.00E+00	0.00E+00
800	3.27E-03	3.53E-03	0.00E+00	3.27E-03	0.00E+00	0.00E+00	0.00E+00
900	3.88E-03	4.14E-03	0.00E+00	3.88E-03	0.00E+00	0.00E+00	0.00E+00
1,000	4.50E-03	4.76E-03	0.00E+00	4.50E-03	0.00E+00	0.00E+00	0.00E+00
2,000	1.06E-02	1.09E-02	0.00E+00	1.06E-02	0.00E+00	0.00E+00	0.00E+00
3,000	1.68E-02	1.71E-02	1.03E-03	1.68E-02	0.00E+00	0.00E+00	0.00E+00
4,000	2.29E-02	2.32E-02	4.50E-03	2.29E-02	0.00E+00	0.00E+00	0.00E+00
5,000	2.91E-02	2.94E-02	7.97E-03	2.91E-02	0.00E+00	0.00E+00	0.00E+00
6,000	3.52E-02	3.56E-02	1.14E-02	3.52E-02	0.00E+00	0.00E+00	0.00E+00
7,000	4.14E-02	4.17E-02	1.49E-02	4.14E-02	0.00E+00	0.00E+00	0.00E+00
8,000	4.75E-02	4.79E-02	1.84E-02	4.75E-02	0.00E+00	0.00E+00	0.00E+00
9,000	5.37E-02	5.40E-02	2.18E-02	5.37E-02	0.00E+00	0.00E+00	0.00E+00
10,000	5.98E-02	6.02E-02	2.53E-02	5.98E-02	0.00E+00	0.00E+00	0.00E+00

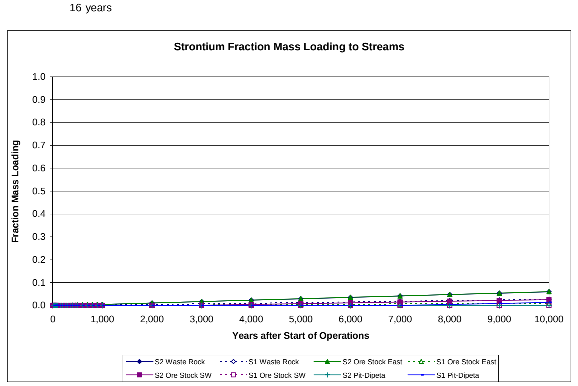
Loading Calculations to Kasana (kg/year)

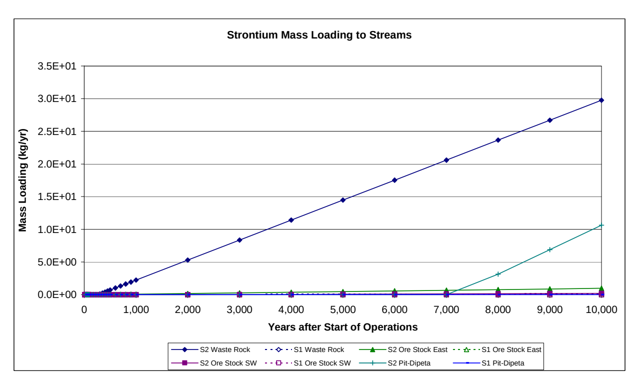
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	2.22E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	9.62E-02	0.00E+00	7.22E-03	0.00E+00	0.00E+00	0.00E+00	5.12E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	2.49E-01	0.00E+00	1.22E-02	0.00E+00	0.00E+00	0.00E+00	1.33E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	4.02E-01	0.00E+00	1.72E-02	0.00E+00	0.00E+00	0.00E+00	2.14E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	5.55E-01	0.00E+00	2.22E-02	0.00E+00	0.00E+00	0.00E+00	2.95E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	7.08E-01	0.00E+00	2.73E-02	0.00E+00	0.00E+00	0.00E+00	3.77E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	1.01E+00	4.48E-04	3.73E-02	0.00E+00	0.00E+00	0.00E+00	5.39E-06	8.30E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	1.32E+00	2.27E-03	4.73E-02	0.00E+00	0.00E+00	0.00E+00	7.02E-06	4.21E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	1.63E+00	4.09E-03	5.73E-02	0.00E+00	0.00E+00	0.00E+00	8.65E-06	7.58E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	1.93E+00	5.91E-03	6.73E-02	0.00E+00	0.00E+00	0.00E+00	1.03E-05	1.10E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	2.24E+00	7.73E-03	7.73E-02	0.00E+00	0.00E+00	0.00E+00	1.19E-05	1.43E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	5.30E+00	2.59E-02	1.77E-01	4.14E-04	0.00E+00	0.00E+00	2.82E-05	4.81E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	8.35E+00	4.42E-02	2.78E-01	9.46E-04	8.41E-03	0.00E+00	4.44E-05	8.19E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	1.14E+01	6.24E-02	3.78E-01	1.48E-03	3.66E-02	0.00E+00	6.07E-05	1.16E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	1.45E+01	8.06E-02	4.78E-01	2.01E-03	6.47E-02	0.00E+00	7.70E-05	1.49E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	1.75E+01	9.88E-02	5.78E-01	2.54E-03	9.29E-02	0.00E+00	9.33E-05	1.83E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	2.06E+01	1.17E-01	6.78E-01	3.07E-03	1.21E-01	0.00E+00	1.10E-04	2.17E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	2.36E+01	1.35E-01	7.78E-01	3.60E-03	1.49E-01	0.00E+00	1.26E-04	2.51E-06	0.00E+00	0.00E+00	3.13E+00	0.00E+00	0.00E+00	0.00E+00
9,000	2.67E+01	1.53E-01	8.78E-01	4.14E-03	1.77E-01	0.00E+00	1.42E-04	2.84E-06	0.00E+00	0.00E+00	6.88E+00	0.00E+00	0.00E+00	0.00E+00
10,000	2.98E+01	1.72E-01	9.78E-01	4.67E-03	2.06E-01	0.00E+00	1.58E-04	3.18E-06	0.00E+00	0.00E+00	1.06E+01	0.00E+00	0.00E+00	0.00E+00

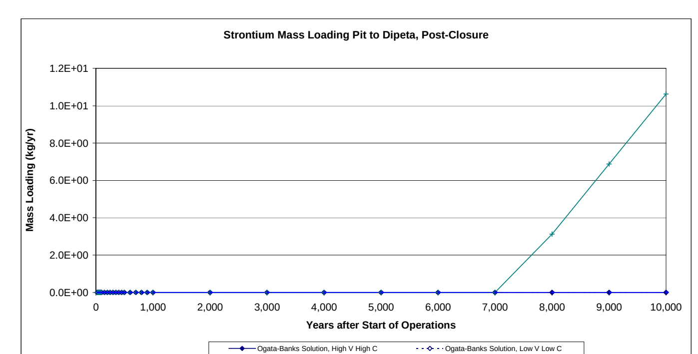
Ogata-Banks Solution

Time from Start of Operations (Years)*	High V High C – Post-closure Loading to Dipeta, Scenario 1 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)	Low V Low C – Post-closure Loading to Dipeta, Scenario 2 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)
0						
10						
16						
20	N/A	N/A	0	N/A	N/A	0
30	N/A	N/A	0	N/A	N/A	0
40	N/A	N/A	0	N/A	N/A	0
50	N/A	N/A	0	N/A	N/A	0
60	1.16E+02	0.0	0.00E+00	1.45E+02	0.0	0.00E+00
70	8.22E+01	0.0	0.00E+00	1.03E+02	0.0	0.00E+00
80	6.71E+01	0.0	0.00E+00	8.39E+01	0.0	0.00E+00
90	5.81E+01	0.0	0.00E+00	7.26E+01	0.0	0.00E+00
100	5.19E+01	0.0	0.00E+00	6.50E+01	0.0	0.00E+00
150	3.67E+01	0.0	0.00E+00	4.59E+01	0.0	0.00E+00
200	2.99E+01	0.0	0.00E+00	3.75E+01	0.0	0.00E+00
250	2.59E+01	0.0	0.00E+00	3.24E+01	0.0	0.00E+00
300	2.31E+01	0.0	0.00E+00	2.90E+01	0.0	0.00E+00
350	2.11E+01	0.0	0.00E+00	2.64E+01	0.0	0.00E+00
400	1.95E+01	0.0	0.00E+00	2.45E+01	0.0	0.00E+00
450	1.82E+01	0.0	0.00E+00	2.29E+01	0.0	0.00E+00
500	1.72E+01	0.0	0.00E+00	2.15E+01	0.0	0.00E+00
600	1.55E+01	0.0	0.00E+00	1.95E+01	0.0	0.00E+00
700	1.42E+01	0.0	0.00E+00	1.79E+01	0.0	0.00E+00
800	1.32E+01	0.0	0.00E+00	1.66E+01	0.0	0.00E+00
900	1.24E+01	0.0	0.00E+00	1.56E+01	0.0	0.00E+00
1,000	1.17E+01	0.0	0.00E+00	1.47E+01	0.0	0.00E+00
2,000	8.03E+00	0.0	0.00E+00	1.02E+01	0.0	0.00E+00
3,000	6.40E+00	0.0	0.00E+00	8.17E+00	0.0	0.00E+00
4,000	5.42E+00	0.0	0.00E+00	6.97E+00	0.0	0.00E+00
5,000	4.75E+00	0.0	0.00E+00	6.15E+00	0.0	0.00E+00
6,000	4.24E+00	0.0	0.00E+00	5.54E+00	0.0	0.00E+00
7,000	3.84E+00	0.0	0.00E+00	5.06E+00	0.0	0.00E+00
8,000	3.52E+00	0.0	0.00E+00	4.67E+00	0.0	0.00E+00
9,000	3.24E+00	0.0	0.00E+00	4.34E+00	0.0	0.00E+00
10,000	3.01E+00	0.0	0.00E+00	4.06E+00	0.0	0.00E+00

* End of operational period: 16 years







DATA SHEET 17 - vanadium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	4771		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation **16**
Years to Pit Flow-Through **50**

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	575	269
	1	349,026	162,879
Ore Stockpile East	0	1,221	228
	1	870,723	162,535
Ore Stockpile Southwest	0	N/A	2,701
	1	N/A	291,214
Tailings Facility	0	575	269
	1	349,026	162,879
ROM Ore Stockpiles	0	N/A	30,888
	1	N/A	378,606
Pit to Dipeta	0	7,117	11,092
	1	211,560	330,534
Pit to Mofia	0	N/A	42,634
	1	N/A	715,210

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	458.44508	210171.8912	575.419278
	b	194.74	285.07	Scenario 2	313.177611	98080.21588	268.528996
	c	-95420	-95420				
Full Contribution	a	0.03	0.06	Scenario 1	11290.79	127,481,871	349,026
	b	-194.74	-285.07	Scenario 2	7713.08	59,491,540	162,879
	c	-1526720	-1526720				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	667.700343	445,824	1,221
	b	134.37	311.01	Scenario 2	288.479519	83,220	228
	c	-95420	-95420				
Full Contribution	a	0.01	0.07	Scenario 1	17833.44	318,031,675	870,723
	b	-134.37	-311.01	Scenario 2	7704.93	59,365,913	162,535
	c	-1669850	-1669850				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	310.90	Scenario 2	993.321862	986,688	2,701
	c	-357825	-357825				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-310.90	Scenario 2	10313.3803	106,365,812	291,214
	c	-2075385	-2075385				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	458.4451	210,172	575
	b	194.74	285.07	Scenario 2	313.1776	98,080	269
	c	-95420	-95420				
Full Contribu	a	0.03	0.06	Scenario 1	11290.79	127,481,871	349,026
	b	-194.74	-285.07	Scenario 2	7713.076	59,491,540	162,879
	c	-1526720	-1526720				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	401.38	Scenario 2	3358.86	11,281,939	30,888
	c	-1908400	-1908400				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-401.38	Scenario 2	11759.5	138,285,868	378,606
	c	-2146950	-2146950				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	1606.616	2,581,215	7,117
	b	577.34	461.87	Scenario 2	2008.27	4,033,148	11,092
	c	-1192750	-1192750				
Full Contribu	a	0.10	0.07	Scenario 1	8789.42	77,253,911	211,560
	b	-577.34	-461.87	Scenario 2	10986.78	120,709,236	330,534
	c	-2862600	-2862600				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	442.80	Scenario 2	3943.817	15,553,691	42,634
	c	-2385500	-2385500				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-577.34	-442.80	Scenario 2	16162.06	261,212,250	715,210
	c	-3578250	-3578250				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Scenario 1

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	7.05E-05	0.00E+00	0.00E+00	7.05E-05	0.00E+00	0.00E+00	0.00E+00
700	3.58E-04	0.00E+00	0.00E+00	3.58E-04	0.00E+00	0.00E+00	0.00E+00
800	6.45E-04	0.00E+00	0.00E+00	6.45E-04	0.00E+00	0.00E+00	0.00E+00
900	9.31E-04	0.00E+00	0.00E+00	9.31E-04	0.00E+00	0.00E+00	0.00E+00
1,000	1.22E-03	0.00E+00	0.00E+00	1.22E-03	0.00E+00	0.00E+00	0.00E+00
2,000	4.09E-03	8.96E-04	0.00E+00	4.09E-03	0.00E+00	0.00E+00	0.00E+00
3,000	6.96E-03	2.05E-03	0.00E+00	6.96E-03	0.00E+00	0.00E+00	0.00E+00
4,000	9.83E-03	3.20E-03	0.00E+00	9.83E-03	0.00E+00	0.00E+00	0.00E+00
5,000	1.27E-02	4.35E-03	0.00E+00	1.27E-02	0.00E+00	0.00E+00	0.00E+00
6,000	1.56E-02	5.50E-03	0.00E+00	1.56E-02	0.00E+00	0.00E+00	0.00E+00
7,000	1.84E-02	6.65E-03	0.00E+00	1.84E-02	0.00E+00	0.00E+00	0.00E+00
8,000	2.13E-02	7.80E-03	0.00E+00	2.13E-02	0.00E+00	4.07E-03	0.00E+00
9,000	2.42E-02	8.95E-03	0.00E+00	2.42E-02	0.00E+00	8.97E-03	0.00E+00
10,000	2.70E-02	1.01E-02	0.00E+00	2.70E-02	0.00E+00	1.39E-02	0.00E+00

Scenario 2

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	1.36E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	1.94E-04	4.45E-04	0.00E+00	1.94E-04	0.00E+00	0.00E+00	0.00E+00
350	5.01E-04	7.53E-04	0.00E+00	5.01E-04	0.00E+00	0.00E+00	0.00E+00
400	8.09E-04	1.06E-03	0.00E+00	8.09E-04	0.00E+00	0.00E+00	0.00E+00
450	1.12E-03	1.37E-03	0.00E+00	1.12E-03	0.00E+00	0.00E+00	0.00E+00
500	1.42E-03	1.68E-03	0.00E+00	1.42E-03	0.00E+00	0.00E+00	0.00E+00
600	2.04E-03	2.29E-03	0.00E+00	2.04E-03	0.00E+00	0.00E+00	0.00E+00
700	2.65E-03	2.91E-03	0.00E+00	2.65E-03	0.00E+00	0.00E+00	0.00E+00
800	3.27E-03	3.53E-03	0.00E+00	3.27E-03	0.00E+00	0.00E+00	0.00E+00
900	3.88E-03	4.14E-03	0.00E+00	3.88E-03	0.00E+00	0.00E+00	0.00E+00
1,000	4.50E-03	4.76E-03	0.00E+00	4.50E-03	0.00E+00	0.00E+00	0.00E+00
2,000	1.06E-02	1.09E-02	0.00E+00	1.06E-02	0.00E+00	0.00E+00	0.00E+00
3,000	1.68E-02	1.71E-02	1.03E-03	1.68E-02	0.00E+00	0.00E+00	0.00E+00
4,000	2.29E-02	2.32E-02	4.50E-03	2.29E-02	0.00E+00	0.00E+00	0.00E+00
5,000	2.91E-02	2.94E-02	7.97E-03	2.91E-02	0.00E+00	0.00E+00	0.00E+00
6,000	3.52E-02	3.56E-02	1.14E-02	3.52E-02	0.00E+00	0.00E+00	0.00E+00
7,000	4.14E-02	4.17E-02	1.49E-02	4.14E-02	0.00E+00	0.00E+00	0.00E+00
8,000	4.75E-02	4.79E-02	1.84E-02	4.75E-02	0.00E+00	0.00E+00	0.00E+00
9,000	5.37E-02	5.40E-02	2.18E-02	5.37E-02	0.00E+00	0.00E+00	0.00E+00
10,000	5.98E-02	6.02E-02	2.53E-02	5.98E-02	0.00E+00	0.00E+00	0.00E+00

Loading Calculations to Kasana (kg/year)

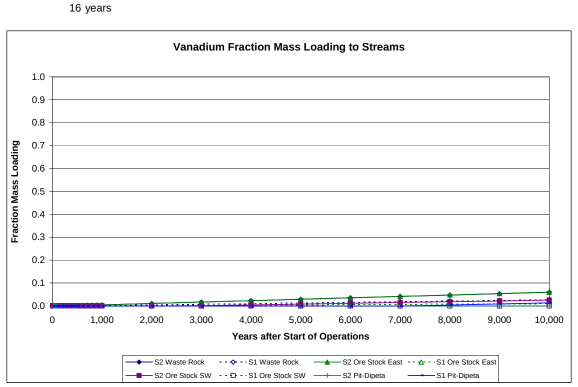
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	2.46E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	6.53E-04	0.00E+00	8.03E-04	0.00E+00	0.00E+00	0.00E+00	5.80E-10	0.00E+00
350	1.69E-03	0.00E+00	1.36E-03	0.00E+00	0.00E+00	0.00E+00	1.50E-09	0.00E+00
400	2.73E-03	0.00E+00	1.92E-03	0.00E+00	0.00E+00	0.00E+00	2.42E-09	0.00E+00
450	3.77E-03	0.00E+00	2.47E-03	0.00E+00	0.00E+00	0.00E+00	3.35E-09	0.00E+00
500	4.81E-03	0.00E+00	3.03E-03	0.00E+00	0.00E+00	0.00E+00	4.27E-09	0.00E+00
600	6.88E-03	2.33E-05	4.14E-03	0.00E+00	0.00E+00	0.00E+00	6.11E-09	1.41E-11
700	8.96E-03	1.18E-04	5.25E-03	0.00E+00	0.00E+00	0.00E+00	7.96E-09	7.16E-11
800	1.10E-02	2.13E-04	6.37E-03	0.00E+00	0.00E+00	0.00E+00	9.80E-09	1.29E-10
900	1.31E-02	3.07E-04	7.48E-03	0.00E+00	0.00E+00	0.00E+00	1.16E-08	1.86E-10
1,000	1.52E-02	4.02E-04	8.59E-03	0.00E+00	0.00E+00	0.00E+00	1.35E-08	2.44E-10
2,000	3.60E-02	1.35E-03	1.97E-02	1.63E-04	0.00E+00	0.00E+00	3.19E-08	8.18E-10
3,000	5.67E-02	2.30E-03	3.08E-02	3.72E-04	9.34E-04	0.00E+00	5.04E-08	1.39E-09
4,000	7.75E-02	3.24E-03	4.20E-02	5.82E-04	4.06E-03	0.00E+00	6.88E-08	1.97E-09
5,000	9.82E-02	4.19E-03	5.31E-02	7.91E-04	7.19E-03	0.00E+00	8.73E-08	2.54E-09
6,000	1.19E-01	5.14E-03	6.42E-02	1.00E-03	1.03E-02	0.00E+00	1.06E-07	3.12E-09
7,000	1.40E-01	6.09E-03	7.53E-02	1.21E-03	1.35E-02	0.00E+00	1.24E-07	3.69E-09
8,000	1.61E-01	7.03E-03	8.65E-02	1.42E-03	1.66E-02	0.00E+00	1.43E-07	4.26E-09
9,000	1.81E-01	7.98E-03	9.76E-02	1.63E-03	1.97E-02	0.00E+00	1.61E-07	4.84E-09
10,000	2.02E-01	8.93E-03	1.09E-01	1.84E-03	2.28E-02	0.00E+00	1.79E-07	5.41E-09

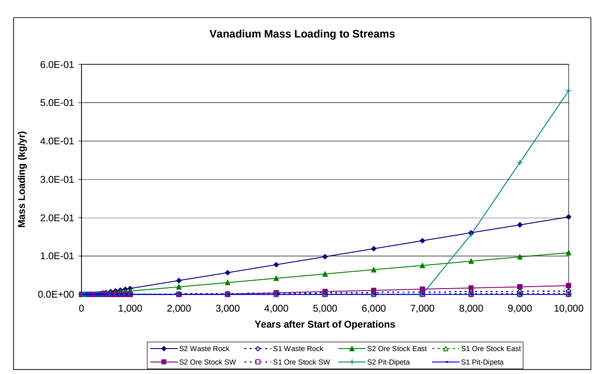
Loading Calculations to Kasana (kg/year) (continued)

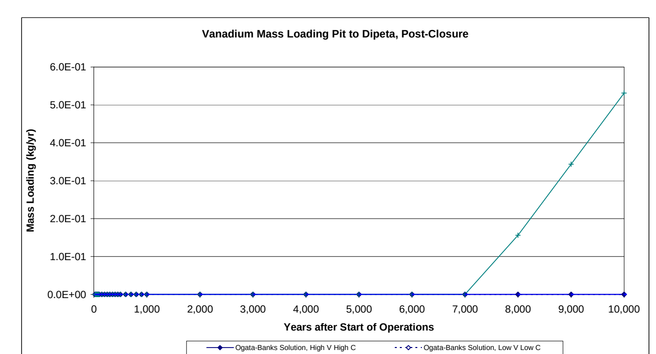
Time from Start of Operations (Years)*	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	0.00E+00	0.00E+00	1.56E-01	0.00E+00	0.00E+00	0.00E+00
9,000	0.00E+00	0.00E+00	3.44E-01	0.00E+00	0.00E+00	0.00E+00
10,000	0.00E+00	0.00E+00	5.31E-01	0.00E+00	0.00E+00	0.00E+00

Ogata-Banks Solution, High V High C — Post-closure Loading to Dipeta, Scenario 1 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)	Ogata-Banks Solution, Low V Low C — Post-closure Loading to Dipeta, Scenario 2 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
1.16E+02	0.0	0.00E+00	1.45E+02	0.0	0.00E+00
8.22E+01	0.0	0.00E+00	1.03E+02	0.0	0.00E+00
6.71E+01	0.0	0.00E+00	8.39E+01	0.0	0.00E+00
5.81E+01	0.0	0.00E+00	7.26E+01	0.0	0.00E+00
5.19E+01	0.0	0.00E+00	6.50E+01	0.0	0.00E+00
3.67E+01	0.0	0.00E+00	4.59E+01	0.0	0.00E+00
2.99E+01	0.0	0.00E+00	3.75E+01	0.0	0.00E+00
2.59E+01	0.0	0.00E+00	3.24E+01	0.0	0.00E+00
2.31E+01	0.0	0.00E+00	2.90E+01	0.0	0.00E+00
2.11E+01	0.0	0.00E+00	2.64E+01	0.0	0.00E+00
1.95E+01	0.0	0.00E+00	2.45E+01	0.0	0.00E+00
1.82E+01	0.0	0.00E+00	2.29E+01	0.0	0.00E+00
1.72E+01	0.0	0.00E+00	2.15E+01	0.0	0.00E+00
1.55E+01	0.0	0.00E+00	1.95E+01	0.0	0.00E+00
1.42E+01	0.0	0.00E+00	1.79E+01	0.0	0.00E+00
1.32E+01	0.0	0.00E+00	1.66E+01	0.0	0.00E+00
1.24E+01	0.0	0.00E+00	1.56E+01	0.0	0.00E+00
1.17E+01	0.0	0.00E+00	1.47E+01	0.0	0.00E+00
8.03E+00	0.0	0.00E+00	1.02E+01	0.0	0.00E+00
6.40E+00	0.0	0.00E+00	8.17E+00	0.0	0.00E+00
5.42E+00	0.0	0.00E+00	6.97E+00	0.0	0.00E+00
4.75E+00	0.0	0.00E+00	6.15E+00	0.0	0.00E+00
4.24E+00	0.0	0.00E+00	5.54E+00	0.0	0.00E+00
3.84E+00	0.0	0.00E+00	5.06E+00	0.0	0.00E+00
3.52E+00	0.0	0.00E+00	4.67E+00	0.0	0.00E+00
3.24E+00	0.0	0.00E+00	4.34E+00	0.0	0.00E+00
3.01E+00	0.0	0.00E+00	4.06E+00	0.0	0.00E+00

* End of operational period: 16 years







DATA SHEET 18 - molybdenum

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	5725		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	690	322
	1	418,817	195,448
Ore Stockpile East	0	1,465	273
	1	1,044,831	195,035
Ore Stockpile Southwest	0	N/A	3,242
	1	N/A	349,444
Tailings Facility	0	690	322
	1	418,817	195,448
ROM Ore Stockpiles	0	N/A	37,065
	1	N/A	454,311
Pit to Dipeta	0	8,530	13,300
	1	253,853	396,617
Pit to Mofia	0	N/A	51,149
	1	N/A	858,212

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	502.192651	252197.459	690.479012
	b	213.32	312.27	Scenario 2	343.062892	117692.1475	322.223539
	c	-114500	-114500				
Full Contribution	a	0.03	0.06	Scenario 1	12368.22	152,972,901	418,817
	b	-213.32	-312.27	Scenario 2	8449.10	71,387,354	195,448
	c	-1832000	-1832000				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	731.416303	534,970	1,465
	b	147.19	340.69	Scenario 2	316.00796	99,861	273
	c	-114500	-114500				
Full Contribution	a	0.01	0.07	Scenario 1	19535.22	381,624,678	1,044,831
	b	-147.19	-340.69	Scenario 2	8440.18	71,236,607	195,035
	c	-2003750	-2003750				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	340.57	Scenario 2	1088.11058	1,183,985	3,242
	c	-429375	-429375				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-340.57	Scenario 2	11297.5447	127,634,516	349,444
	c	-2490375	-2490375				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	502.1927	252,197	690
	b	213.32	312.27	Scenario 2	343.0629	117,692	322
	c	-114500	-114500				
Full Contribution	a	0.03	0.06	Scenario 1	12368.22	152,972,901	418,817
	b	-213.32	-312.27	Scenario 2	8449.104	71,387,354	195,448
	c	-1832000	-1832000				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	439.68	Scenario 2	3679.382	13,537,854	37,065
	c	-2290000	-2290000				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-439.68	Scenario 2	12881.66	165,937,245	454,311
	c	-2576250	-2576250				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	1759.929	3,097,350	8,530
	b	632.43	505.94	Scenario 2	2199.911	4,839,609	13,300
	c	-1431250	-1431250				
Full Contribution	a	0.10	0.07	Scenario 1	9628.16	92,701,454	253,853
	b	-632.43	-505.94	Scenario 2	12035.20	144,846,022	396,617
	c	-3435000	-3435000				

Pit to Mofia, Post-closure

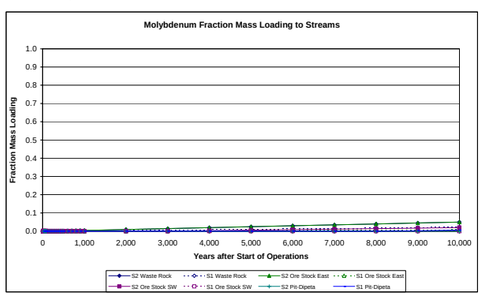
	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	485.05	Scenario 2	4320.159	18,663,778	51,149
	c	-2862500	-2862500				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-632.43	-485.05	Scenario 2	17704.34	313,443,750	858,212
	c	-4293750	-4293750				

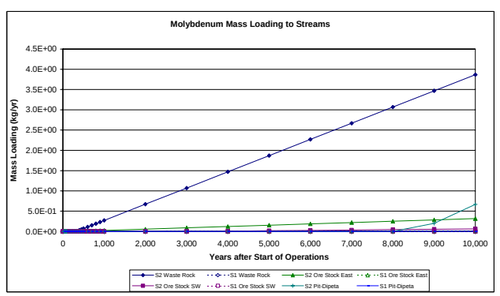
a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

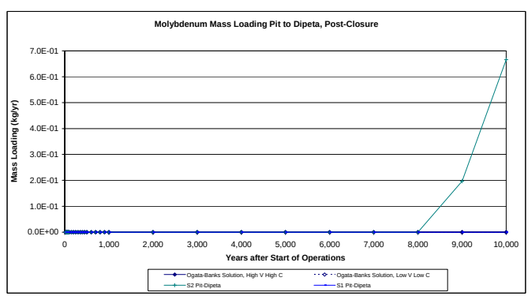
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading	Loading Calculations to Kasana (kg/year): Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.27E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.63E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-04	3.93E-04	0.00E+00	1.42E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.48E-03	0.00E+00	0.00E+00	6.01E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.99E-04	6.50E-04	0.00E+00	3.99E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.11E-03	0.00E+00	0.00E+00	1.68E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.55E-04	9.07E-04	0.00E+00	6.55E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.73E-03	0.00E+00	0.00E+00	2.76E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.11E-04	1.16E-03	0.00E+00	9.11E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.35E-03	0.00E+00	0.00E+00	3.85E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-03	1.68E-03	0.00E+00	1.42E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.06E-02	0.00E+00	0.00E+00	6.01E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	2.28E-05	0.00E+00	0.00E+00	2.28E-05	0.00E+00	0.00E+00	0.00E+00	1.94E-03	2.19E-03	0.00E+00	1.94E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E-02	0.00E+00	0.00E+00	8.17E-07	2.07E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	2.62E-04	0.00E+00	0.00E+00	2.62E-04	0.00E+00	0.00E+00	0.00E+00	2.45E-03	2.70E-03	0.00E+00	2.45E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.84E-02	0.00E+00	0.00E+00	1.03E-06	2.38E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	5.01E-04	0.00E+00	0.00E+00	5.01E-04	0.00E+00	0.00E+00	0.00E+00	2.96E-03	3.22E-03	0.00E+00	2.96E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.22E-02	0.00E+00	0.00E+00	1.25E-06	4.55E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	7.40E-04	0.00E+00	0.00E+00	7.40E-04	0.00E+00	0.00E+00	0.00E+00	3.47E-03	3.73E-03	0.00E+00	3.47E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.71E-02	0.00E+00	0.00E+00	1.47E-06	6.72E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	3.13E-03	5.13E-04	0.00E+00	3.13E-03	0.00E+00	0.00E+00	0.00E+00	8.60E-03	8.87E-03	0.00E+00	8.60E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.71E-01	0.00E+00	0.00E+00	3.63E-06	2.84E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	5.52E-03	1.47E-03	0.00E+00	5.52E-03	0.00E+00	0.00E+00	0.00E+00	1.37E-02	1.40E-02	0.00E+00	1.37E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E+00	0.00E+00	0.00E+00	5.79E-06	5.02E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	7.92E-03	2.43E-03	0.00E+00	7.92E-03	0.00E+00	0.00E+00	0.00E+00	1.88E-02	1.91E-02	2.19E-03	1.88E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.47E+00	0.00E+00	0.00E+00	7.96E-06	7.19E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	1.03E-02	3.39E-03	0.00E+00	1.03E-02	0.00E+00	0.00E+00	0.00E+00	2.40E-02	2.43E-02	5.08E-03	2.40E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.87E+00	0.00E+00	0.00E+00	1.01E-05	9.36E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	1.27E-02	4.35E-03	0.00E+00	1.27E-02	0.00E+00	0.00E+00	0.00E+00	2.91E-02	2.94E-02	7.97E-03	2.91E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E+00	0.00E+00	0.00E+00	1.23E-05	1.15E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	1.51E-02	5.31E-03	0.00E+00	1.51E-02	0.00E+00	0.00E+00	0.00E+00	3.42E-02	3.45E-02	1.09E-02	3.42E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.67E+00	0.00E+00	0.00E+00	1.06E-02	2.18E-01	1.19E-03	3.43E-02	0.00E+00	1.44E-05	1.37E-07	0.00E+00	0.00E+00	0.00E+00
8,000	1.75E-02	6.26E-03	0.00E+00	1.75E-02	0.00E+00	0.00E+00	0.00E+00	3.93E-02	3.97E-02	1.37E-02	3.93E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.07E+00	0.00E+00	0.00E+00	1.23E-02	2.51E-01	1.40E-03	4.34E-02	0.00E+00	1.66E-05	1.59E-07	0.00E+00	0.00E+00	0.00E+00
9,000	1.99E-02	7.22E-03	0.00E+00	1.99E-02	0.00E+00	1.71E-03	0.00E+00	4.45E-02	4.48E-02	1.66E-02	4.45E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.47E+00	0.00E+00	0.00E+00	1.39E-02	2.83E-01	1.62E-03	5.25E-02	0.00E+00	1.88E-05	1.80E-07	0.00E+00	0.00E+00	0.00E+00
10,000	2.23E-02	8.18E-03	0.00E+00	2.23E-02	0.00E+00	5.79E-03	0.00E+00	4.96E-02	4.99E-02	1.95E-02	4.96E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.87E+00	0.00E+00	0.00E+00	1.56E-02	3.16E-01	1.83E-03	6.17E-02	0.00E+00	2.09E-05	2.02E-07	0.00E+00	0.00E+00	0.00E+00

* End of operational period: 16 years

Ogata-Banks Solution, High V High C: Post-closure Loading to Dipeta, Scenario 1 (kg/yr)			Ogata-Banks Solution, Low V Low C: Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)	Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
1.27E+02	0.0	0.00E+00	1.59E+02	0.0	0.00E+00
9.00E+01	0.0	0.00E+00	1.13E+02	0.0	0.00E+00
7.35E+01	0.0	0.00E+00	9.19E+01	0.0	0.00E+00
6.36E+01	0.0	0.00E+00	7.96E+01	0.0	0.00E+00
5.69E+01	0.0	0.00E+00	7.12E+01	0.0	0.00E+00
4.02E+01	0.0	0.00E+00	5.03E+01	0.0	0.00E+00
3.28E+01	0.0	0.00E+00	4.10E+01	0.0	0.00E+00
2.84E+01	0.0	0.00E+00	3.55E+01	0.0	0.00E+00
2.54E+01	0.0	0.00E+00	3.18E+01	0.0	0.00E+00
2.31E+01	0.0	0.00E+00	2.90E+01	0.0	0.00E+00
2.14E+01	0.0	0.00E+00	2.68E+01	0.0	0.00E+00
2.00E+01	0.0	0.00E+00	2.51E+01	0.0	0.00E+00
1.89E+01	0.0	0.00E+00	2.36E+01	0.0	0.00E+00
1.70E+01	0.0	0.00E+00	2.14E+01	0.0	0.00E+00
1.56E+01	0.0	0.00E+00	1.96E+01	0.0	0.00E+00
1.45E+01	0.0	0.00E+00	1.82E+01	0.0	0.00E+00
1.36E+01	0.0	0.00E+00	1.71E+01	0.0	0.00E+00
1.29E+01	0.0	0.00E+00	1.62E+01	0.0	0.00E+00
8.85E+00	0.0	0.00E+00	1.12E+01	0.0	0.00E+00
7.08E+00	0.0	0.00E+00	9.00E+00	0.0	0.00E+00
6.02E+00	0.0	0.00E+00	7.70E+00	0.0	0.00E+00
5.29E+00	0.0	0.00E+00	6.81E+00	0.0	0.00E+00
4.74E+00	0.0	0.00E+00	6.14E+00	0.0	0.00E+00
4.31E+00	0.0	0.00E+00	5.62E+00	0.0	0.00E+00
3.96E+00	0.0	0.00E+00	5.20E+00	0.0	0.00E+00
3.67E+00	0.0	0.00E+00	4.85E+00	0.0	0.00E+00
3.42E+00	0.0	0.00E+00	4.55E+00	0.0	0.00E+00







DATA SHEET 19 - cadmium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	20178		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	2,434	1,136
	1	1,476,145	688,868
Ore Stockpile East	0	5,162	964
	1	3,682,570	687,413
Ore Stockpile Southwest	0	N/A	11,425
	1	N/A	1,231,637
Tailings Facility	0	2,434	1,136
	1	1,476,145	688,868
ROM Ore Stockpiles	0	N/A	130,636
	1	N/A	1,601,247
Pit to Dipeta	0	29,939	46,751
	1	894,593	1,397,773
Pit to Mofia	0	N/A	180,150
	1	N/A	3,024,693

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	942.806879	888884.8119	2433.63398
	b	400.49	586.26	Scenario 2	644.059712	414812.9122	1135.69586
	c	-403562	-403562				
Full Contribution	a	0.03	0.06	Scenario 1	23219.86	539,162,009	1,476,145
	b	-400.49	-586.26	Scenario 2	15862.19	251,608,937	688,868
	c	-6456992	-6456992				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	1373.14698	1,885,533	5,162
	b	276.34	639.60	Scenario 2	593.267301	351,966	964
	c	-403562	-403562				
Full Contribution	a	0.01	0.07	Scenario 1	36675.04	1,345,058,675	3,682,570
	b	-276.34	-639.60	Scenario 2	15845.43	251,077,619	687,413
	c	-7062335	-7062335				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	639.39	Scenario 2	2042.79798	4,173,024	11,425
	c	-1513357.5	-1513357.5				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-639.39	Scenario 2	21209.7943	449,855,376	1,231,637
	c	-8777473.5	-8777473.5				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	942.8069	888,885	2,434
	b	400.49	586.26	Scenario 2	644.0597	414,813	1,136
	c	-403562	-403562				
Full Contribution	a	0.03	0.06	Scenario 1	23219.86	539,162,009	1,476,145
	b	-400.49	-586.26	Scenario 2	15862.19	251,608,937	688,868
	c	-6456992	-6456992				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	825.44	Scenario 2	6907.602	47,714,963	130,636
	c	-8071240	-8071240				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-825.44	Scenario 2	24183.79	584,855,602	1,601,247
	c	-9080145	-9080145				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	3304.057	10,916,792	29,939
	b	1187.31	949.85	Scenario 2	4130.071	17,057,487	46,751
	c	-5044525	-5044525				
Full Contribution	a	0.10	0.07	Scenario 1	18075.72	326,731,741	894,593
	b	-1187.31	-949.85	Scenario 2	22594.65	510,518,345	1,397,773
	c	-12106860	-12106860				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	910.62	Scenario 2	8110.585	65,781,585	180,150
	c	-10089050	-10089050				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-1187.31	-910.62	Scenario 2	33237.79	1,104,750,975	3,024,693
	c	-15133575	-15133575				

Scenario 1

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	3.84E-04	0.00E+00	0.00E+00	3.84E-04	0.00E+00	0.00E+00	0.00E+00
4,000	1.06E-03	0.00E+00	0.00E+00	1.06E-03	0.00E+00	0.00E+00	0.00E+00
5,000	1.74E-03	0.00E+00	0.00E+00	1.74E-03	0.00E+00	0.00E+00	0.00E+00
6,000	2.42E-03	2.28E-04	0.00E+00	2.42E-03	0.00E+00	0.00E+00	0.00E+00
7,000	3.10E-03	5.00E-04	0.00E+00	3.10E-03	0.00E+00	0.00E+00	0.00E+00
8,000	3.78E-03	7.72E-04	0.00E+00	3.78E-03	0.00E+00	0.00E+00	0.00E+00
9,000	4.46E-03	1.04E-03	0.00E+00	4.46E-03	0.00E+00	0.00E+00	0.00E+00
10,000	5.13E-03	1.32E-03	0.00E+00	5.13E-03	0.00E+00	0.00E+00	0.00E+00

Scenario 2

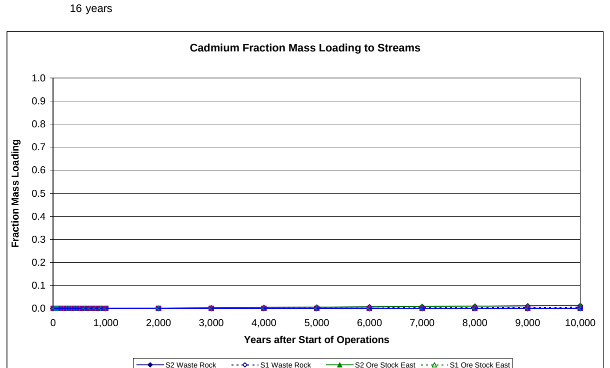
Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	5.30E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	1.26E-03	1.51E-03	0.00E+00	1.26E-03	0.00E+00	0.00E+00	0.00E+00
3,000	2.71E-03	2.97E-03	0.00E+00	2.71E-03	0.00E+00	0.00E+00	0.00E+00
4,000	4.16E-03	4.42E-03	0.00E+00	4.16E-03	0.00E+00	0.00E+00	0.00E+00
5,000	5.62E-03	5.88E-03	0.00E+00	5.62E-03	0.00E+00	0.00E+00	0.00E+00
6,000	7.07E-03	7.34E-03	0.00E+00	7.07E-03	0.00E+00	0.00E+00	0.00E+00
7,000	8.53E-03	8.79E-03	0.00E+00	8.53E-03	0.00E+00	0.00E+00	0.00E+00
8,000	9.98E-03	1.03E-02	0.00E+00	9.98E-03	0.00E+00	0.00E+00	0.00E+00
9,000	1.14E-02	1.17E-02	0.00E+00	1.14E-02	0.00E+00	0.00E+00	0.00E+00
10,000	1.29E-02	1.32E-02	0.00E+00	1.29E-02	0.00E+00	0.00E+00	0.00E+00

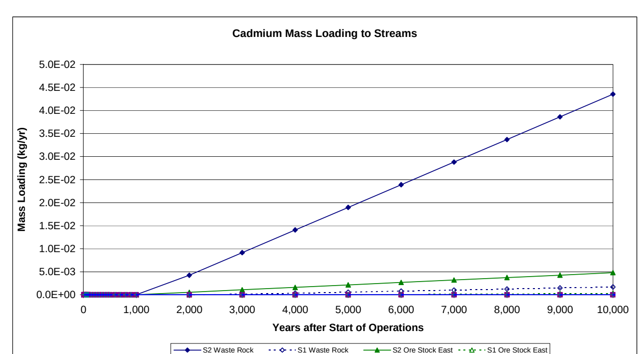
Loading Calculations to Kasana (kg/year)

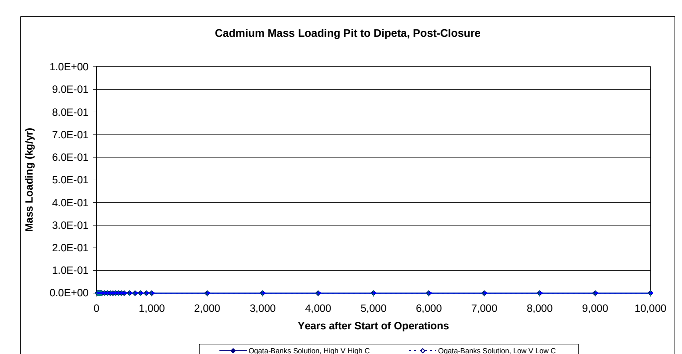
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	1.93E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	4.24E-03	0.00E+00	5.50E-04	0.00E+00	0.00E+00	0.00E+00	2.52E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	9.15E-03	1.27E-04	1.08E-03	0.00E+00	0.00E+00	0.00E+00	5.43E-10	7.69E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	1.41E-02	3.51E-04	1.61E-03	0.00E+00	0.00E+00	0.00E+00	8.34E-10	2.13E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	1.90E-02	5.75E-04	2.14E-03	0.00E+00	0.00E+00	0.00E+00	1.12E-09	3.49E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	2.39E-02	7.99E-04	2.67E-03	5.11E-05	0.00E+00	0.00E+00	1.42E-09	4.84E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	2.88E-02	1.02E-03	3.20E-03	1.12E-04	0.00E+00	0.00E+00	1.71E-09	6.20E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	3.37E-02	1.25E-03	3.73E-03	1.73E-04	0.00E+00	0.00E+00	2.00E-09	7.56E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9,000	3.86E-02	1.47E-03	4.26E-03	2.34E-04	0.00E+00	0.00E+00	2.29E-09	8.92E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10,000	4.35E-02	1.69E-03	4.80E-03	2.95E-04	0.00E+00	0.00E+00	2.58E-09	1.03E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Time from Start of Operations (Years)*	Ogata-Banks Solution, High V High C — Post-closure Loading to Dipeta, Scenario 1 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)	Ogata-Banks Solution, Low V Low C — Post-closure Loading to Dipeta, Scenario 2 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)
0						
10						
16						
20	N/A	N/A	0	N/A	N/A	0
30	N/A	N/A	0	N/A	N/A	0
40	N/A	N/A	0	N/A	N/A	0
50	N/A	N/A	0	N/A	N/A	0
60	2.39E+02	0.0	0.00E+00	2.99E+02	0.0	0.00E+00
70	1.69E+02	0.0	0.00E+00	2.11E+02	0.0	0.00E+00
80	1.38E+02	0.0	0.00E+00	1.73E+02	0.0	0.00E+00
90	1.20E+02	0.0	0.00E+00	1.49E+02	0.0	0.00E+00
100	1.07E+02	0.0	0.00E+00	1.34E+02	0.0	0.00E+00
150	7.56E+01	0.0	0.00E+00	9.45E+01	0.0	0.00E+00
200	6.17E+01	0.0	0.00E+00	7.71E+01	0.0	0.00E+00
250	5.34E+01	0.0	0.00E+00	6.68E+01	0.0	0.00E+00
300	4.78E+01	0.0	0.00E+00	5.97E+01	0.0	0.00E+00
350	4.36E+01	0.0	0.00E+00	5.45E+01	0.0	0.00E+00
400	4.04E+01	0.0	0.00E+00	5.05E+01	0.0	0.00E+00
450	3.77E+01	0.0	0.00E+00	4.72E+01	0.0	0.00E+00
500	3.56E+01	0.0	0.00E+00	4.45E+01	0.0	0.00E+00
600	3.22E+01	0.0	0.00E+00	4.02E+01	0.0	0.00E+00
700	2.96E+01	0.0	0.00E+00	3.70E+01	0.0	0.00E+00
800	2.75E+01	0.0	0.00E+00	3.44E+01	0.0	0.00E+00
900	2.58E+01	0.0	0.00E+00	3.23E+01	0.0	0.00E+00
1,000	2.44E+01	0.0	0.00E+00	3.06E+01	0.0	0.00E+00
2,000	1.70E+01	0.0	0.00E+00	2.13E+01	0.0	0.00E+00
3,000	1.37E+01	0.0	0.00E+00	1.73E+01	0.0	0.00E+00
4,000	1.18E+01	0.0	0.00E+00	1.49E+01	0.0	0.00E+00
5,000	1.05E+01	0.0	0.00E+00	1.32E+01	0.0	0.00E+00
6,000	9.55E+00	0.0	0.00E+00	1.20E+01	0.0	0.00E+00
7,000	8.79E+00	0.0	0.00E+00	1.11E+01	0.0	0.00E+00
8,000	8.19E+00	0.0	0.00E+00	1.04E+01	0.0	0.00E+00
9,000	7.68E+00	0.0	0.00E+00	9.74E+00	0.0	0.00E+00
10,000	7.25E+00	0.0	0.00E+00	9.21E+00	0.0	0.00E+00

* End of operational period: 16 years







DATA SHEET 20 - mercury

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	27667		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	3,337	1,557
	1	2,024,002	944,534
Ore Stockpile East	0	7,078	1,321
	1	5,049,319	942,540
Ore Stockpile Southwest	0	N/A	15,665
	1	N/A	1,688,747
Tailings Facility	0	3,337	1,557
	1	2,024,002	944,534
ROM Ore Stockpiles	0	N/A	179,121
	1	N/A	2,195,534
Pit to Dipeta	0	41,031	64,083
	1	1,226,593	1,916,524
Pit to Mofia	0	N/A	246,993
	1	N/A	4,147,259

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	1103.9862	1218785.519	3336.85289
	b	468.96	686.48	Scenario 2	754.166146	568766.5757	1557.19802
	c	-553340	-553340				
Full Contribution	a	0.03	0.06	Scenario 1	27189.46	739,266,596	2,024,002
	b	-468.96	-686.48	Scenario 2	18573.94	344,991,078	944,534
	c	-8853440	-8853440				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	1607.89589	2,585,329	7,078
	b	323.58	748.95	Scenario 2	694.690424	482,595	1,321
	c	-553340	-553340				
Full Contribution	a	0.01	0.07	Scenario 1	42944.89	1,844,263,750	5,049,319
	b	-323.58	-748.95	Scenario 2	18554.31	344,262,567	942,540
	c	-9683450	-9683450				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	748.69	Scenario 2	2392.02834	5,721,800	15,665
	c	-2075025	-2075025				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-748.69	Scenario 2	24835.7545	616,814,699	1,688,747
	c	-12035145	-12035145				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	1103.986	1,218,786	3,337
	b	468.96	686.48	Scenario 2	754.1661	568,767	1,557
	c	-553340	-553340				
Full Contribution	a	0.03	0.06	Scenario 1	27189.46	739,266,596	2,024,002
	b	-468.96	-686.48	Scenario 2	18573.94	344,991,078	944,534
	c	-8853440	-8853440				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	966.56	Scenario 2	8088.504	65,423,894	179,121
	c	-11066800	-11066800				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-966.56	Scenario 2	28318.17	801,918,910	2,195,534
	c	-12450150	-12450150				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	3868.908	14,968,450	41,031
	b	1390.29	1112.23	Scenario 2	4836.135	23,388,203	64,083
	c	-6916750	-6916750				
Full Contribution	a	0.10	0.07	Scenario 1	21165.89	447,994,959	1,226,593
	b	-1390.29	-1112.23	Scenario 2	26457.36	699,992,123	1,916,524
	c	-16600200	-16600200				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	1066.30	Scenario 2	9497.145	90,195,762	246,993
	c	-13833500	-13833500				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-1390.29	-1066.30	Scenario 2	38920.02	1,514,768,250	4,147,259
	c	-20750250	-20750250				

Scenario 1

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	3.28E-04	0.00E+00	0.00E+00	3.28E-04	0.00E+00	0.00E+00	0.00E+00
5,000	8.23E-04	0.00E+00	0.00E+00	8.23E-04	0.00E+00	0.00E+00	0.00E+00
6,000	1.32E-03	0.00E+00	0.00E+00	1.32E-03	0.00E+00	0.00E+00	0.00E+00
7,000	1.81E-03	0.00E+00	0.00E+00	1.81E-03	0.00E+00	0.00E+00	0.00E+00
8,000	2.31E-03	1.83E-04	0.00E+00	2.31E-03	0.00E+00	0.00E+00	0.00E+00
9,000	2.80E-03	3.81E-04	0.00E+00	2.80E-03	0.00E+00	0.00E+00	0.00E+00
10,000	3.30E-03	5.79E-04	0.00E+00	3.30E-03	0.00E+00	0.00E+00	0.00E+00

Scenario 2

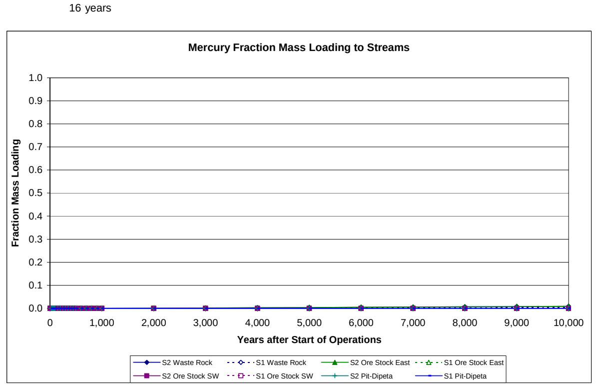
Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	4.70E-04	7.21E-04	0.00E+00	4.70E-04	0.00E+00	0.00E+00	0.00E+00
3,000	1.53E-03	1.78E-03	0.00E+00	1.53E-03	0.00E+00	0.00E+00	0.00E+00
4,000	2.59E-03	2.85E-03	0.00E+00	2.59E-03	0.00E+00	0.00E+00	0.00E+00
5,000	3.65E-03	3.91E-03	0.00E+00	3.65E-03	0.00E+00	0.00E+00	0.00E+00
6,000	4.71E-03	4.97E-03	0.00E+00	4.71E-03	0.00E+00	0.00E+00	0.00E+00
7,000	5.77E-03	6.03E-03	0.00E+00	5.77E-03	0.00E+00	0.00E+00	0.00E+00
8,000	6.83E-03	7.10E-03	0.00E+00	6.83E-03	0.00E+00	0.00E+00	0.00E+00
9,000	7.89E-03	8.16E-03	0.00E+00	7.89E-03	0.00E+00	0.00E+00	0.00E+00
10,000	8.95E-03	9.22E-03	0.00E+00	8.95E-03	0.00E+00	0.00E+00	0.00E+00

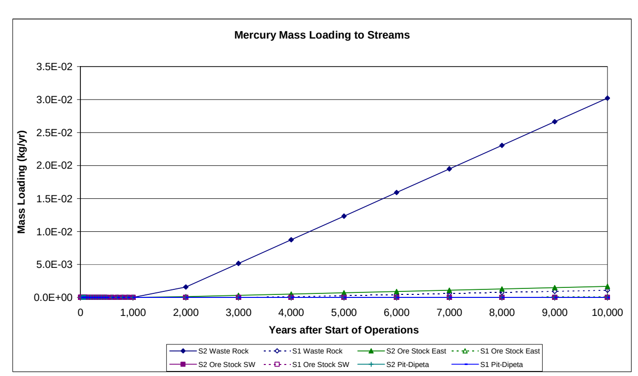
Loading Calculations to Kasana (kg/year)

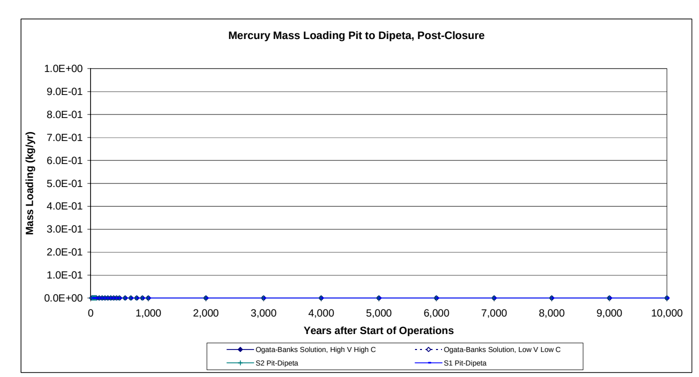
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	1.59E-03	0.00E+00	1.31E-04	0.00E+00	0.00E+00	0.00E+00	9.40E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	5.17E-03	0.00E+00	3.25E-04	0.00E+00	0.00E+00	0.00E+00	3.06E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	8.75E-03	1.08E-04	5.18E-04	0.00E+00	0.00E+00	0.00E+00	5.18E-10	6.57E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	1.23E-02	2.72E-04	7.12E-04	0.00E+00	0.00E+00	0.00E+00	7.31E-10	1.65E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	1.59E-02	4.35E-04	9.05E-04	0.00E+00	0.00E+00	0.00E+00	9.43E-10	2.64E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	1.95E-02	5.98E-04	1.10E-03	0.00E+00	0.00E+00	0.00E+00	1.16E-09	3.63E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	2.31E-02	7.62E-04	1.29E-03	3.33E-05	0.00E+00	0.00E+00	1.37E-09	4.62E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9,000	2.66E-02	9.25E-04	1.49E-03	6.94E-05	0.00E+00	0.00E+00	1.58E-09	5.61E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10,000	3.02E-02	1.09E-03	1.68E-03	1.06E-04	0.00E+00	0.00E+00	1.79E-09	6.60E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Time from Start of Operations (Years)*	Ogata-Banks Solution, High V High C — Post-closure Loading to Dipeta, Scenario 1 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)	Ogata-Banks Solution, Low V Low C — Post-closure Loading to Dipeta, Scenario 2 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)
0						
10						
16						
20	N/A	N/A	0	N/A	N/A	0
30	N/A	N/A	0	N/A	N/A	0
40	N/A	N/A	0	N/A	N/A	0
50	N/A	N/A	0	N/A	N/A	0
60	2.80E+02	0.0	0.00E+00	3.50E+02	0.0	0.00E+00
70	1.98E+02	0.0	0.00E+00	2.47E+02	0.0	0.00E+00
80	1.62E+02	0.0	0.00E+00	2.02E+02	0.0	0.00E+00
90	1.40E+02	0.0	0.00E+00	1.75E+02	0.0	0.00E+00
100	1.25E+02	0.0	0.00E+00	1.56E+02	0.0	0.00E+00
150	8.85E+01	0.0	0.00E+00	1.11E+02	0.0	0.00E+00
200	7.23E+01	0.0	0.00E+00	9.03E+01	0.0	0.00E+00
250	6.26E+01	0.0	0.00E+00	7.82E+01	0.0	0.00E+00
300	5.60E+01	0.0	0.00E+00	7.00E+01	0.0	0.00E+00
350	5.11E+01	0.0	0.00E+00	6.39E+01	0.0	0.00E+00
400	4.73E+01	0.0	0.00E+00	5.91E+01	0.0	0.00E+00
450	4.42E+01	0.0	0.00E+00	5.53E+01	0.0	0.00E+00
500	4.17E+01	0.0	0.00E+00	5.21E+01	0.0	0.00E+00
600	3.77E+01	0.0	0.00E+00	4.71E+01	0.0	0.00E+00
700	3.47E+01	0.0	0.00E+00	4.34E+01	0.0	0.00E+00
800	3.23E+01	0.0	0.00E+00	4.03E+01	0.0	0.00E+00
900	3.03E+01	0.0	0.00E+00	3.79E+01	0.0	0.00E+00
1,000	2.86E+01	0.0	0.00E+00	3.58E+01	0.0	0.00E+00
2,000	1.99E+01	0.0	0.00E+00	2.50E+01	0.0	0.00E+00
3,000	1.61E+01	0.0	0.00E+00	2.03E+01	0.0	0.00E+00
4,000	1.39E+01	0.0	0.00E+00	1.75E+01	0.0	0.00E+00
5,000	1.24E+01	0.0	0.00E+00	1.56E+01	0.0	0.00E+00
6,000	1.13E+01	0.0	0.00E+00	1.42E+01	0.0	0.00E+00
7,000	1.04E+01	0.0	0.00E+00	1.31E+01	0.0	0.00E+00
8,000	9.68E+00	0.0	0.00E+00	1.22E+01	0.0	0.00E+00
9,000	9.09E+00	0.0	0.00E+00	1.15E+01	0.0	0.00E+00
10,000	8.59E+00	0.0	0.00E+00	1.09E+01	0.0	0.00E+00

* End of operational period: 16 years







DATA SHEET 21 - lead

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	28478		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	3,435	1,603
	1	2,083,324	972,218
Ore Stockpile East	0	7,286	1,360
	1	5,197,311	970,165
Ore Stockpile Southwest	0	N/A	16,125
	1	N/A	1,738,243
Tailings Facility	0	3,435	1,603
	1	2,083,324	972,218
ROM Ore Stockpiles	0	N/A	184,371
	1	N/A	2,259,884
Pit to Dipeta	0	42,233	65,960
	1	1,262,542	1,972,694
Pit to Mofia	0	N/A	254,230
	1	N/A	4,268,811

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	1120.04788	1254507.252	3434.65367
	b	475.78	696.47	Scenario 2	765.138365	585436.7177	1602.83838
	c	-569558	-569558				
Full Contribution	a	0.03	0.06	Scenario 1	27585.03	760,933,971	2,083,324
	b	-475.78	-696.47	Scenario 2	18844.16	355,102,520	972,218
	c	-9112928	-9112928				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	1631.28886	2,661,103	7,286
	b	328.29	759.84	Scenario 2	704.797342	496,739	1,360
	c	-569558	-569558				
Full Contribution	a	0.01	0.07	Scenario 1	43569.69	1,898,317,802	5,197,311
	b	-328.29	-759.84	Scenario 2	18824.26	354,352,656	970,165
	c	-9967265	-9967265				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	759.59	Scenario 2	2426.8295	5,889,501	16,125
	c	-2135842.5	-2135842.5				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-759.59	Scenario 2	25197.0851	634,893,097	1,738,243
	c	-12387886.5	-12387886.5				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	1120.048	1,254,507	3,435
	b	475.78	696.47	Scenario 2	765.1384	585,437	1,603
	c	-569558	-569558				
Full Contribution	a	0.03	0.06	Scenario 1	27585.03	760,933,971	2,083,324
	b	-475.78	-696.47	Scenario 2	18844.16	355,102,520	972,218
	c	-9112928	-9112928				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	980.62	Scenario 2	8206.182	67,341,422	184,371
	c	-11391160	-11391160				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-980.62	Scenario 2	28730.17	825,422,580	2,259,884
	c	-12815055	-12815055				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	3925.196	15,407,165	42,233
	b	1410.51	1128.41	Scenario 2	4906.495	24,073,695	65,960
	c	-7119475	-7119475				
Full Contribution	a	0.10	0.07	Scenario 1	21473.83	461,125,371	1,262,542
	b	-1410.51	-1128.41	Scenario 2	26842.29	720,508,392	1,972,694
	c	-17086740	-17086740				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	1081.82	Scenario 2	9635.317	92,839,335	254,230
	c	-14238950	-14238950				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-1410.51	-1081.82	Scenario 2	39486.26	1,559,165,025	4,268,811
	c	-21358425	-21358425				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.09E-04	6.61E-04	0.00E+00	4.09E-04	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.44E-03	1.69E-03	0.00E+00	1.44E-03	0.00E+00	0.00E+00	0.00E+00
4,000	2.72E-04	0.00E+00	0.00E+00	2.72E-04	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.73E-03	0.00E+00	2.47E-03	0.00E+00	0.00E+00	0.00E+00
5,000	7.53E-04	0.00E+00	0.00E+00	7.53E-04	0.00E+00	0.00E+00	0.00E+00	3.50E-03	3.76E-03	0.00E+00	3.50E-03	0.00E+00	0.00E+00	0.00E+00
6,000	1.23E-03	0.00E+00	0.00E+00	1.23E-03	0.00E+00	0.00E+00	0.00E+00	4.53E-03	4.79E-03	0.00E+00	4.53E-03	0.00E+00	0.00E+00	0.00E+00
7,000	1.71E-03	0.00E+00	0.00E+00	1.71E-03	0.00E+00	0.00E+00	0.00E+00	5.56E-03	5.82E-03	0.00E+00	5.56E-03	0.00E+00	0.00E+00	0.00E+00
8,000	2.19E-03	1.38E-04	0.00E+00	2.19E-03	0.00E+00	0.00E+00	0.00E+00	6.59E-03	6.85E-03	0.00E+00	6.59E-03	0.00E+00	0.00E+00	0.00E+00
9,000	2.68E-03	3.30E-04	0.00E+00	2.68E-03	0.00E+00	0.00E+00	0.00E+00	7.62E-03	7.89E-03	0.00E+00	7.62E-03	0.00E+00	0.00E+00	0.00E+00
10,000	3.16E-03	5.23E-04	0.00E+00	3.16E-03	0.00E+00	0.00E+00	0.00E+00	8.65E-03	8.92E-03	0.00E+00	8.65E-03	0.00E+00	0.00E+00	0.00E+00

* End of operational period: 16 years

Loading Calculations to Kasana (kg/year)

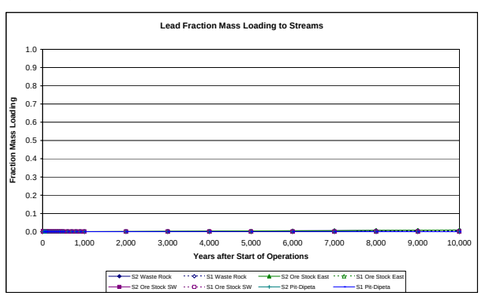
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	8.63E-03	0.00E+00	1.19E-03	0.00E+00	0.00E+00	9.58E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	3.03E-02	0.00E+00	3.06E-03	0.00E+00	0.00E+00	3.37E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	5.21E-02	1.69E-04	4.92E-03	0.00E+00	0.00E+00	5.78E-10	5.44E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	7.38E-02	4.68E-04	6.79E-03	0.00E+00	0.00E+00	8.19E-10	1.51E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	9.55E-02	7.67E-04	8.66E-03	0.00E+00	0.00E+00	1.06E-09	2.47E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	1.17E-01	1.07E-03	1.05E-02	0.00E+00	0.00E+00	1.30E-09	3.43E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	1.39E-01	1.36E-03	1.24E-02	2.51E-05	0.00E+00	1.54E-09	4.39E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9,000	1.61E-01	1.66E-03	1.43E-02	6.02E-05	0.00E+00	1.78E-09	5.36E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10,000	1.82E-01	1.96E-03	1.61E-02	9.52E-05	0.00E+00	2.03E-09	6.32E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

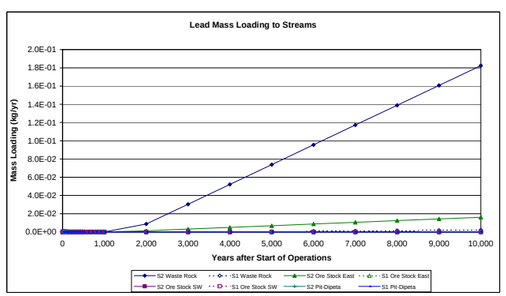
Ogata-Banks Solution, High V High C

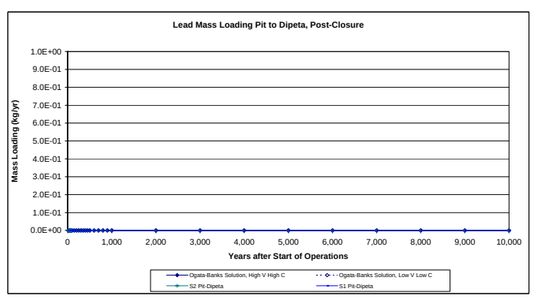
Time from Start of Operations (Years)*	Beta	erfc (Beta)	Mass Loading (kg/yr)
0			
10			
16			
20	N/A	N/A	0
30	N/A	N/A	0
40	N/A	N/A	0
50	N/A	N/A	0
60	2.84E+02	0.0	0.00E+00
70	2.01E+02	0.0	0.00E+00
80	1.64E+02	0.0	0.00E+00
90	1.42E+02	0.0	0.00E+00
100	1.27E+02	0.0	0.00E+00
150	8.98E+01	0.0	0.00E+00
200	7.33E+01	0.0	0.00E+00
250	6.35E+01	0.0	0.00E+00
300	5.68E+01	0.0	0.00E+00
350	5.18E+01	0.0	0.00E+00
400	4.80E+01	0.0	0.00E+00
450	4.49E+01	0.0	0.00E+00
500	4.23E+01	0.0	0.00E+00
600	3.82E+01	0.0	0.00E+00
700	3.52E+01	0.0	0.00E+00
800	3.27E+01	0.0	0.00E+00
900	3.07E+01	0.0	0.00E+00
1,000	2.91E+01	0.0	0.00E+00
2,000	2.02E+01	0.0	0.00E+00
3,000	1.64E+01	0.0	0.00E+00
4,000	1.41E+01	0.0	0.00E+00
5,000	1.26E+01	0.0	0.00E+00
6,000	1.14E+01	0.0	0.00E+00
7,000	1.05E+01	0.0	0.00E+00
8,000	9.83E+00	0.0	0.00E+00
9,000	9.23E+00	0.0	0.00E+00
10,000	8.73E+00	0.0	0.00E+00

Ogata-Banks Solution, Low V Low C

Time from Start of Operations (Years)*	Beta	erfc (Beta)	Mass Loading (kg/yr)
0			
10			
16			
20	N/A	N/A	0
30	N/A	N/A	0
40	N/A	N/A	0
50	N/A	N/A	0
60	3.55E+02	0.0	0.00E+00
70	2.51E+02	0.0	0.00E+00
80	2.05E+02	0.0	0.00E+00
90	1.78E+02	0.0	0.00E+00
100	1.59E+02	0.0	0.00E+00
150	1.12E+02	0.0	0.00E+00
200	9.17E+01	0.0	0.00E+00
250	7.94E+01	0.0	0.00E+00
300	7.10E+01	0.0	0.00E+00
350	6.48E+01	0.0	0.00E+00
400	6.00E+01	0.0	0.00E+00
450	5.61E+01	0.0	0.00E+00
500	5.29E+01	0.0	0.00E+00
600	4.78E+01	0.0	0.00E+00
700	4.40E+01	0.0	0.00E+00
800	4.09E+01	0.0	0.00E+00
900	3.84E+01	0.0	0.00E+00
1,000	3.64E+01	0.0	0.00E+00
2,000	2.53E+01	0.0	0.00E+00
3,000	2.06E+01	0.0	0.00E+00
4,000	1.77E+01	0.0	0.00E+00
5,000	1.58E+01	0.0	0.00E+00
6,000	1.44E+01	0.0	0.00E+00
7,000	1.33E+01	0.0	0.00E+00
8,000	1.24E+01	0.0	0.00E+00
9,000	1.17E+01	0.0	0.00E+00
10,000	1.10E+01	0.0	0.00E+00







DATA SHEET 22 - zinc

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	44791		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	5,402	2,521
	1	3,276,744	1,529,147
Ore Stockpile East	0	11,459	2,139
	1	8,174,560	1,525,918
Ore Stockpile Southwest	0	N/A	25,361
	1	N/A	2,733,985
Tailings Facility	0	5,402	2,521
	1	3,276,744	1,529,147
ROM Ore Stockpiles	0	N/A	289,986
	1	N/A	3,554,445
Pit to Dipeta	0	66,397	103,716
	1	1,985,754	3,102,712
Pit to Mofia	0	N/A	399,836
	1	N/A	6,714,146

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	1404.68661	1973144.462	5402.17512
	b	596.69	873.47	Scenario 2	959.583633	920800.7491	2521.01506
	c	-895826	-895826				
Full Contribution	a	0.03	0.06	Scenario 1	34595.24	1,196,830,587	3,276,744
	b	-596.69	-873.47	Scenario 2	23633.05	558,520,941	1,529,147
	c	-14333216	-14333216				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	2045.8497	4,185,501	11,459
	b	411.72	952.94	Scenario 2	883.908094	781,294	2,139
	c	-895826	-895826				
Full Contribution	a	0.01	0.07	Scenario 1	54642.09	2,985,758,156	8,174,560
	b	-411.72	-952.94	Scenario 2	23608.08	557,341,522	1,525,918
	c	-15676955	-15676955				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	952.62	Scenario 2	3043.56176	9,263,268	25,361
	c	-3359347.5	-3359347.5				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-952.62	Scenario 2	31600.4419	998,587,929	2,733,985
	c	-19484215.5	-19484215.5				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	1404.687	1,973,144	5,402
	b	596.69	873.47	Scenario 2	959.5836	920,801	2,521
	c	-895826	-895826				
Full Contribution	a	0.03	0.06	Scenario 1	34595.24	1,196,830,587	3,276,744
	b	-596.69	-873.47	Scenario 2	23633.05	558,520,941	1,529,147
	c	-14333216	-14333216				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	1229.83	Scenario 2	10291.63	105,917,565	289,986
	c	-17916520	-17916520				
Full Contribution	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-1229.83	Scenario 2	36031.39	1,298,261,122	3,554,445
	c	-20156085	-20156085				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	4922.71	24,233,070	66,397
	b	1768.97	1415.18	Scenario 2	6153.387	37,864,171	103,716
	c	-11197825	-11197825				
Full Contribution	a	0.10	0.07	Scenario 1	26930.99	725,278,367	1,985,754
	b	-1768.97	-1415.18	Scenario 2	33663.74	1,133,247,449	3,102,712
	c	-26874780	-26874780				

Pit to Mofia, Post-closure

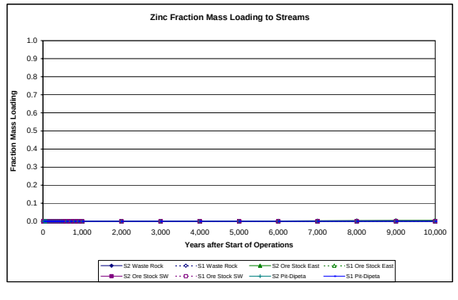
	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	1356.74	Scenario 2	12083.95	146,021,811	399,836
	c	-22395650	-22395650				
Full Contribution	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-1768.97	-1356.74	Scenario 2	49520.94	2,452,323,675	6,714,146
	c	-3359475	-3359475				

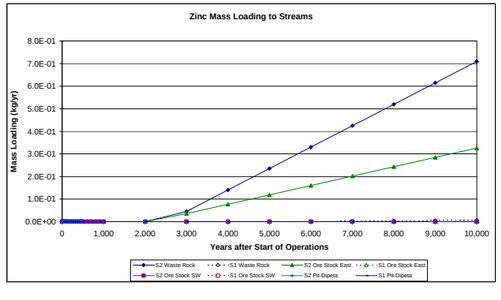
a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

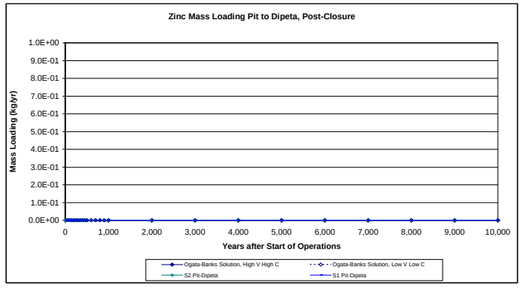
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading	Loading Calculations to Kasana (kg/year): Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.14E-04	5.65E-04	0.00E+00	3.14E-04	0.00E+00	0.00E+00	0.00E+00	4.54E-02	0.00E+00	3.57E-02	0.00E+00	0.00E+00	0.00E+00	7.27E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.06E+01	0.00E+00
4,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.69E-04	1.22E-03	0.00E+00	9.69E-04	0.00E+00	0.00E+00	0.00E+00	1.40E-01	0.00E+00	7.72E-02	0.00E+00	0.00E+00	0.00E+00	2.24E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.58E+01	0.00E+00
5,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-03	1.88E-03	0.00E+00	1.62E-03	0.00E+00	0.00E+00	0.00E+00	2.35E-01	0.00E+00	1.19E-01	0.00E+00	0.00E+00	0.00E+00	3.76E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.23E+01	0.00E+00
6,000	1.83E-04	0.00E+00	0.00E+00	1.83E-04	0.00E+00	0.00E+00	0.00E+00	2.28E-03	2.53E-03	0.00E+00	2.28E-03	0.00E+00	0.00E+00	0.00E+00	3.30E-01	8.52E-04	1.60E-01	0.00E+00	0.00E+00	0.00E+00	5.28E-09	3.66E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.87E+01	0.00E+00
7,000	4.88E-04	0.00E+00	0.00E+00	4.88E-04	0.00E+00	0.00E+00	0.00E+00	2.93E-03	3.19E-03	0.00E+00	2.93E-03	0.00E+00	0.00E+00	0.00E+00	4.25E-01	2.28E-03	2.02E-01	0.00E+00	0.00E+00	0.00E+00	6.80E-09	9.78E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.51E+01	0.00E+00
8,000	7.94E-04	0.00E+00	0.00E+00	7.94E-04	0.00E+00	0.00E+00	0.00E+00	3.59E-03	3.85E-03	0.00E+00	3.59E-03	0.00E+00	0.00E+00	0.00E+00	5.20E-01	3.70E-03	2.43E-01	0.00E+00	0.00E+00	0.00E+00	8.31E-09	1.59E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.16E+01	0.00E+00
9,000	1.10E-03	0.00E+00	0.00E+00	1.10E-03	0.00E+00	0.00E+00	0.00E+00	4.24E-03	4.50E-03	0.00E+00	4.24E-03	0.00E+00	0.00E+00	0.00E+00	6.15E-01	5.13E-03	2.85E-01	0.00E+00	0.00E+00	0.00E+00	9.83E-09	2.20E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.81E+01	0.00E+00
10,000	1.41E-03	0.00E+00	0.00E+00	1.41E-03	0.00E+00	0.00E+00	0.00E+00	4.90E-03	5.16E-03	0.00E+00	4.90E-03	0.00E+00	0.00E+00	0.00E+00	7.09E-01	6.55E-03	3.26E-01	0.00E+00	0.00E+00	0.00E+00	1.13E-08	2.81E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.47E+01	0.00E+00

* End of operational period: 16 years

Ogata-Banks Solution, High V High C: Post-closure Loading to Dipeta, Scenario 1 (kg/yr)				Ogata-Banks Solution, Low V Low C: Post-closure Loading to Dipeta, Scenario 2 (kg/yr)			
Time from Start of Operations (Years)*	Beta	erfc (Beta)	Mass Loading (kg/yr)	Time from Start of Operations (Years)*	Beta	erfc (Beta)	Mass Loading (kg/yr)
0	N/A	N/A	0	0	N/A	N/A	0
10	N/A	N/A	0	10	N/A	N/A	0
16	N/A	N/A	0	**16**	N/A	N/A	0
20	N/A	N/A	0	20	N/A	N/A	0
30	N/A	N/A	0	30	N/A	N/A	0
40	N/A	N/A	0	40	N/A	N/A	0
50	N/A	N/A	0	50	N/A	N/A	0
60	3.56E+02	0.0	0.00E+00	60	4.45E+02	0.0	0.00E+00
70	2.52E+02	0.0	0.00E+00	70	3.15E+02	0.0	0.00E+00
80	2.06E+02	0.0	0.00E+00	80	2.57E+02	0.0	0.00E+00
90	1.78E+02	0.0	0.00E+00	90	2.23E+02	0.0	0.00E+00
100	1.59E+02	0.0	0.00E+00	100	1.99E+02	0.0	0.00E+00
150	1.13E+02	0.0	0.00E+00	150	1.41E+02	0.0	0.00E+00
200	9.20E+01	0.0	0.00E+00	200	1.15E+02	0.0	0.00E+00
250	7.96E+01	0.0	0.00E+00	250	9.95E+01	0.0	0.00E+00
300	7.12E+01	0.0	0.00E+00	300	8.90E+01	0.0	0.00E+00
350	6.50E+01	0.0	0.00E+00	350	8.13E+01	0.0	0.00E+00
400	6.02E+01	0.0	0.00E+00	400	7.52E+01	0.0	0.00E+00
450	5.63E+01	0.0	0.00E+00	450	7.04E+01	0.0	0.00E+00
500	5.31E+01	0.0	0.00E+00	500	6.63E+01	0.0	0.00E+00
600	4.80E+01	0.0	0.00E+00	600	6.00E+01	0.0	0.00E+00
700	4.41E+01	0.0	0.00E+00	700	5.52E+01	0.0	0.00E+00
800	4.11E+01	0.0	0.00E+00	800	5.14E+01	0.0	0.00E+00
900	3.86E+01	0.0	0.00E+00	900	4.82E+01	0.0	0.00E+00
1,000	3.65E+01	0.0	0.00E+00	1,000	4.56E+01	0.0	0.00E+00
2,000	2.54E+01	0.0	0.00E+00	2,000	3.18E+01	0.0	0.00E+00
3,000	2.06E+01	0.0	0.00E+00	3,000	2.58E+01	0.0	0.00E+00
4,000	1.78E+01	0.0	0.00E+00	4,000	2.23E+01	0.0	0.00E+00
5,000	1.59E+01	0.0	0.00E+00	5,000	1.99E+01	0.0	0.00E+00
6,000	1.44E+01	0.0	0.00E+00	6,000	1.81E+01	0.0	0.00E+00
7,000	1.33E+01	0.0	0.00E+00	7,000	1.67E+01	0.0	0.00E+00
8,000	1.24E+01	0.0	0.00E+00	8,000	1.56E+01	0.0	0.00E+00
9,000	1.17E+01	0.0	0.00E+00	9,000	1.47E+01	0.0	0.00E+00
10,000	1.11E+01	0.0	0.00E+00	10,000	1.39E+01	0.0	0.00E+00







Golder Associates

DATA SHEET 23 - sulfate

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	1		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	0	0
	1	73	34
Ore Stockpile East	0	0	0
	1	183	34
Ore Stockpile Southwest	0	N/A	1
	1	N/A	61
Tailings Facility	0	0	0
	1	73	34
ROM Ore Stockpiles	0	N/A	6
	1	N/A	79
Pit to Dipeta	0	51	52
	1	94	119
Pit to Mofia	0	N/A	59
	1	N/A	200

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	6.6371649	44.0519579	0.12060769
	b	2.82	4.13	Scenario 2	4.5340468	20.5575804	0.05628359
	c	-20	-20				
Full Contribu	a	0.03	0.06	Scenario 1	163.46	26,720	73
	b	-2.82	-4.13	Scenario 2	111.67	12,469	34
	c	-320	-320				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	9.66666996	93	0
	b	1.95	4.50	Scenario 2	4.17647876	17	0
	c	-20	-20				
Full Contribu	a	0.01	0.07	Scenario 1	258.18	66,659	183
	b	-1.95	-4.50	Scenario 2	111.55	12,443	34
	c	-350	-350				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	4.50	Scenario 2	14.3808742	207	1
	c	-75	-75				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-4.50	Scenario 2	149.312553	22,294	61
	c	-435	-435				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	6.637165	44	0
	b	2.82	4.13	Scenario 2	4.534047	21	0
	c	-20	-20				
Full Contribu	a	0.03	0.06	Scenario 1	163.463	26,720	73
	b	-2.82	-4.13	Scenario 2	111.6665	12,469	34
	c	-320	-320				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	5.81	Scenario 2	48.62808	2,365	6
	c	-400	-400				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-5.81	Scenario 2	170.2489	28,985	79
	c	-450	-450				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	23.25988	541	51
	b	8.36	6.69	Scenario 2	29.07484	845	52
	c	-250	-250				
Full Contribu	a	0.10	0.07	Scenario 1	127.25	16,192	94
	b	-8.36	-6.69	Scenario 2	159.06	25,301	119
	c	-600	-600				

Pit to Mofia, Post-closure

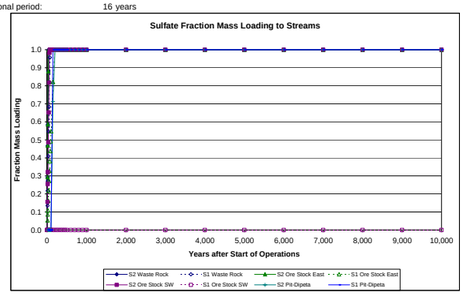
	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	6.41	Scenario 2	57.09683	3,260	59
	c	-500	-500				
Full Contrib	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-8.36	-6.41	Scenario 2	233.99	54,750	200
	c	-750	-750				

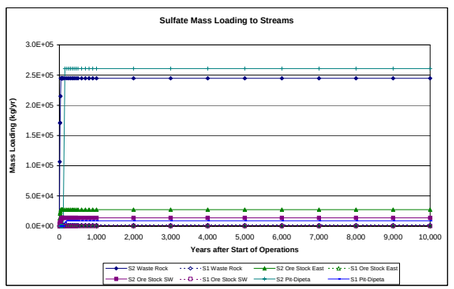
a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

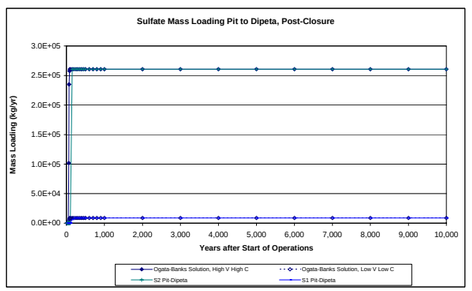
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading	Loading Calculations to Kasana (kg/year): Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00						
10	1.35E-01	5.35E-02	0.00E+00	1.35E-01	0.00E+00			2.92E-01	2.93E-01	1.56E-01	2.92E-01	4.84E-02			1.07E+05	3.49E+02	1.29E+04	4.80E+01	3.45E+03	0.00E+00	0.00E+00	0.00E+00	4.07E+01	0.00E+00						
16	2.17E-01	8.64E-02	0.00E+00	2.17E-01	0.00E+00			4.68E-01	4.69E-01	2.55E-01	4.68E-01	1.31E-01			1.71E+05	5.61E+02	2.08E+04	7.75E+01	5.65E+03	0.00E+00	0.00E+00	0.00E+00	1.10E+02	0.00E+00						
20	2.72E-01	1.08E-01	0.00E+00	2.72E-01	0.00E+00	0.00E+00	0.00E+00	5.85E-01	5.86E-01	3.21E-01	5.85E-01	1.86E-01	0.00E+00	0.00E+00	1.71E+05	5.61E+02	2.08E+04	7.75E+01	5.65E+03	0.00E+00	1.72E+00	4.90E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	4.09E-01	1.63E-01	0.00E+00	4.09E-01	0.00E+00	0.00E+00	0.00E+00	8.79E-01	8.80E-01	4.87E-01	8.79E-01	3.23E-01	0.00E+00	0.00E+00	2.56E+05	7.08E+02	2.38E+04	8.96E+01	6.59E+03	0.00E+00	2.58E+00	7.36E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	5.46E-01	2.18E-01	0.00E+00	5.46E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	6.52E-01	1.00E+00	4.60E-01	0.00E+00	0.00E+00	2.45E+05	9.45E+02	2.71E+04	1.20E+02	8.83E+03	0.00E+00	2.94E+00	9.82E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	6.83E-01	2.73E-01	0.00E+00	6.83E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	8.17E-01	1.00E+00	5.97E-01	0.00E+00	0.00E+00	2.45E+05	1.18E+03	2.71E+04	1.50E+02	1.11E+04	0.00E+00	2.94E+00	1.23E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	8.20E-01	3.28E-01	0.00E+00	8.20E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	9.83E-01	1.00E+00	7.34E-01	0.00E+00	0.00E+00	2.45E+05	1.42E+03	2.71E+04	1.80E+02	1.33E+04	0.00E+00	2.94E+00	1.48E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	9.57E-01	3.83E-01	0.00E+00	9.57E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	8.72E-01	0.00E+00	0.00E+00	2.45E+05	1.66E+03	2.71E+04	2.10E+02	1.35E+04	0.00E+00	2.94E+00	1.72E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	1.00E+00	4.38E-01	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	2.45E+05	1.73E+03	2.71E+04	2.40E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	1.00E+00	4.92E-01	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	2.45E+05	1.73E+03	2.71E+04	2.70E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	1.00E+00	5.47E-01	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	2.45E+05	1.73E+03	2.71E+04	3.01E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	1.00E+00	8.22E-01	0.00E+00	1.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	7.12E-01	2.91E-01	2.45E+05	1.73E+03	2.71E+04	4.51E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	6.26E+03	1.34E+04	2.56E+03	0.00E+00	0.00E+00
200	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	6.46E-01	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	2.97E+04	5.68E+03	0.00E+00	0.00E+00
250	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
300	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
350	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
400	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
450	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
500	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
600	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
700	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
800	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
900	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
1,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
2,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
3,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
4,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
5,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
6,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
7,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
8,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
9,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00
10,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.45E+05	1.73E+03	2.71E+04	5.49E+02	1.35E+04	0.00E+00	2.94E+00	1.80E-01	0.00E+00	0.00E+00	2.61E+05	8.78E+03	4.59E+04	8.78E+03	0.00E+00	0.00E+00

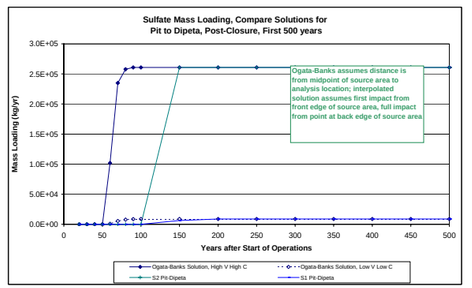
* End of operational period: 16 years

Ogata-Banks Solution, High V High C			Ogata-Banks Solution, Low V Low C		
Post-closure Loading to Dipeta, Scenario 1 (kg/yr)			Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)	Beta	erfc (Beta)	Mass Loading (kg/yr)
		0	N/A	N/A	0
		0	N/A	N/A	0
		0	N/A	N/A	0
		0	N/A	N/A	0
1.97E-01	0.8	1.02E+05	9.15E-01	0.2	8.59E+02
-9.12E-01	1.8	2.35E+05	-1.94E-01	1.2	5.34E+03
-1.60E+00	2.0	2.58E+05	-8.45E-01	1.8	7.76E+03
-2.13E+00	2.0	2.61E+05	-1.33E+00	1.9	8.52E+03
-2.57E+00	2.0	2.61E+05	-1.72E+00	2.0	8.72E+03
-4.17E+00	2.0	2.61E+05	-3.09E+00	2.0	8.78E+03
-5.32E+00	2.0	2.61E+05	-4.06E+00	2.0	8.78E+03
-6.27E+00	2.0	2.61E+05	-4.85E+00	2.0	8.78E+03
-7.09E+00	2.0	2.61E+05	-5.52E+00	2.0	8.78E+03
-7.83E+00	2.0	2.61E+05	-6.13E+00	2.0	8.78E+03
-8.51E+00	2.0	2.61E+05	-6.68E+00	2.0	8.78E+03
-9.13E+00	2.0	2.61E+05	-7.19E+00	2.0	8.78E+03
-9.72E+00	2.0	2.61E+05	-7.66E+00	2.0	8.78E+03
-1.08E+01	2.0	2.61E+05	-8.53E+00	2.0	8.78E+03
-1.18E+01	2.0	2.61E+05	-9.32E+00	2.0	8.78E+03
-1.27E+01	2.0	2.61E+05	-1.01E+01	2.0	8.78E+03
-1.35E+01	2.0	2.61E+05	-1.07E+01	2.0	8.78E+03
-1.43E+01	2.0	2.61E+05	-1.14E+01	2.0	8.78E+03
-2.06E+01	2.0	2.61E+05	-1.65E+01	2.0	8.78E+03
-2.54E+01	2.0	2.61E+05	-2.03E+01	2.0	8.78E+03
-2.95E+01	2.0	2.61E+05	-2.35E+01	2.0	8.78E+03
-3.30E+01	2.0	2.61E+05	-2.64E+01	2.0	8.78E+03
-3.62E+01	2.0	2.61E+05	-2.89E+01	2.0	8.78E+03
-3.91E+01	2.0	2.61E+05	-3.13E+01	2.0	8.78E+03
-4.18E+01	2.0	2.61E+05	-3.34E+01	2.0	8.78E+03
-4.44E+01	2.0	2.61E+05	-3.55E+01	2.0	8.78E+03
-4.68E+01	2.0	2.61E+05	-3.74E+01	2.0	8.78E+03









DATA SHEET 24 - potassium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	11		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	1	1
	1	771	360
Ore Stockpile East	0	3	1
	1	1,924	359
Ore Stockpile Southwest	0	N/A	6
	1	N/A	643
Tailings Facility	0	1	1
	1	771	360
ROM Ore Stockpiles	0	N/A	68
	1	N/A	836
Pit to Dipeta	0	66	74
	1	517	780
Pit to Mofia	0	N/A	144
	1	N/A	1,630

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	21.5477989	464.307636	1.27120503
	b	9.15	13.40	Scenario 2	14.7199489	216.676897	0.59322901
	c	-210.8	-210.8				
Full Contribu	a	0.03	0.06	Scenario 1	530.69	281,630	771
	b	-9.15	-13.40	Scenario 2	362.53	131,428	360
	c	-3372.8	-3372.8				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	31.383198	985	3
	b	6.32	14.62	Scenario 2	13.5590912	184	1
	c	-210.8	-210.8				
Full Contribu	a	0.01	0.07	Scenario 1	838.21	702,589	1,924
	b	-6.32	-14.62	Scenario 2	362.15	131,150	359
	c	-3689	-3689				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	14.61	Scenario 2	46.6880345	2,180	6
	c	-790.5	-790.5				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-14.61	Scenario 2	484.748672	234,981	643
	c	-4584.9	-4584.9				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	21.5478	464	1
	b	9.15	13.40	Scenario 2	14.71995	217	1
	c	-210.8	-210.8				
Full Contrib	a	0.03	0.06	Scenario 1	530.6887	281,630	771
	b	-9.15	-13.40	Scenario 2	362.5294	131,428	360
	c	-3372.8	-3372.8				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	18.87	Scenario 2	157.8729	24,924	68
	c	-4216	-4216				
Full Contrib	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-18.87	Scenario 2	552.7191	305,498	836
	c	-4743	-4743				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	75.51404	5,702	66
	b	27.14	21.71	Scenario 2	94.39255	8,910	74
	c	-2635	-2635				
Full Contrib	a	0.10	0.07	Scenario 1	413.12	170,668	517
	b	-27.14	-21.71	Scenario 2	516.40	266,668	780
	c	-6324	-6324				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	20.81	Scenario 2	185.367	34,361	144
	c	-5270	-5270				
Full Contrib	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-27.14	-20.81	Scenario 2	759.65	577,065	1,630
	c	-7905	-7905				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

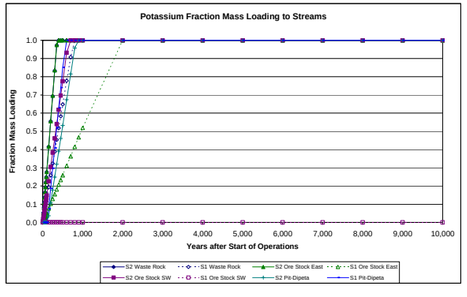
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	1.13E-02	3.80E-03	0.00E+00	1.13E-02	0.00E+00			2.62E-02	2.65E-02	6.33E-03	2.62E-02	0.00E+00		
16	1.91E-02	6.93E-03	0.00E+00	1.91E-02	0.00E+00			4.29E-02	4.32E-02	1.57E-02	4.29E-02	0.00E+00		
20	2.43E-02	9.01E-03	0.00E+00	2.43E-02	0.00E+00	0.00E+00	0.00E+00	5.40E-02	5.44E-02	2.20E-02	5.40E-02	0.00E+00	0.00E+00	0.00E+00
30	3.73E-02	1.42E-02	0.00E+00	3.73E-02	0.00E+00	0.00E+00	0.00E+00	8.19E-02	8.23E-02	3.77E-02	8.19E-02	0.00E+00	0.00E+00	0.00E+00
40	5.03E-02	1.94E-02	0.00E+00	5.03E-02	0.00E+00	0.00E+00	0.00E+00	1.10E-01	1.10E-01	5.34E-02	1.10E-01	0.00E+00	0.00E+00	0.00E+00
50	6.33E-02	2.46E-02	0.00E+00	6.33E-02	0.00E+00	0.00E+00	0.00E+00	1.38E-01	1.38E-01	6.91E-02	1.38E-01	0.00E+00	0.00E+00	0.00E+00
60	7.63E-02	2.98E-02	0.00E+00	7.63E-02	0.00E+00	0.00E+00	0.00E+00	1.65E-01	1.66E-01	8.48E-02	1.65E-01	0.00E+00	0.00E+00	0.00E+00
70	8.93E-02	3.50E-02	0.00E+00	8.93E-02	0.00E+00	0.00E+00	0.00E+00	1.93E-01	1.94E-01	1.00E-01	1.93E-01	2.29E-03	0.00E+00	0.00E+00
80	1.02E-01	4.02E-02	0.00E+00	1.02E-01	0.00E+00	0.00E+00	0.00E+00	2.21E-01	2.22E-01	1.16E-01	2.21E-01	1.53E-02	0.00E+00	0.00E+00
90	1.15E-01	4.54E-02	0.00E+00	1.15E-01	0.00E+00	0.00E+00	0.00E+00	2.49E-01	2.50E-01	1.32E-01	2.49E-01	2.83E-02	0.00E+00	0.00E+00
100	1.28E-01	5.07E-02	0.00E+00	1.28E-01	0.00E+00	0.00E+00	0.00E+00	2.77E-01	2.77E-01	1.48E-01	2.77E-01	4.13E-02	0.00E+00	0.00E+00
150	1.93E-01	7.67E-02	0.00E+00	1.93E-01	0.00E+00	7.61E-02	0.00E+00	4.16E-01	4.17E-01	2.26E-01	4.16E-01	1.06E-01	3.63E-02	0.00E+00
200	2.58E-01	1.03E-01	0.00E+00	2.58E-01	0.00E+00	1.87E-01	0.00E+00	5.55E-01	5.56E-01	3.04E-01	5.55E-01	1.72E-01	1.07E-01	3.99E-03
250	3.23E-01	1.29E-01	0.00E+00	3.23E-01	0.00E+00	2.98E-01	0.00E+00	6.94E-01	6.96E-01	3.83E-01	6.94E-01	2.37E-01	1.78E-01	3.76E-02
300	3.88E-01	1.55E-01	0.00E+00	3.88E-01	0.00E+00	4.08E-01	0.00E+00	8.33E-01	8.35E-01	4.61E-01	8.33E-01	3.02E-01	2.49E-01	7.13E-02
350	4.53E-01	1.81E-01	0.00E+00	4.53E-01	0.00E+00	5.19E-01	0.00E+00	9.73E-01	9.75E-01	5.40E-01	9.73E-01	3.67E-01	3.20E-01	1.05E-01
400	5.18E-01	2.07E-01	0.00E+00	5.18E-01	0.00E+00	6.30E-01	0.00E+00	1.00E+00	1.00E+00	6.18E-01	1.00E+00	4.32E-01	3.91E-01	1.39E-01
450	5.83E-01	2.33E-01	0.00E+00	5.83E-01	0.00E+00	7.40E-01	0.00E+00	1.00E+00	1.00E+00	6.97E-01	1.00E+00	4.97E-01	4.61E-01	1.72E-01
500	6.48E-01	2.59E-01	0.00E+00	6.48E-01	0.00E+00	8.51E-01	0.00E+00	1.00E+00	1.00E+00	7.75E-01	1.00E+00	5.62E-01	5.32E-01	2.06E-01
600	7.78E-01	3.11E-01	0.00E+00	7.78E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	9.32E-01	1.00E+00	6.92E-01	6.74E-01	2.73E-01
700	9.08E-01	3.63E-01	0.00E+00	9.08E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	8.22E-01	8.16E-01	3.40E-01
800	1.00E+00	4.15E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.53E-01	9.57E-01	4.08E-01
900	1.00E+00	4.67E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.75E-01
1,000	1.00E+00	5.19E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	5.42E-01
2,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
3,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
4,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
5,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
6,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
7,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
8,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
9,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
10,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00

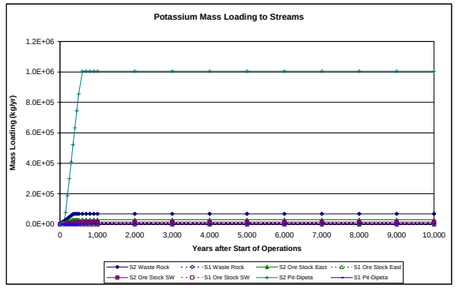
Loading Calculations to Kasana (kg/year)

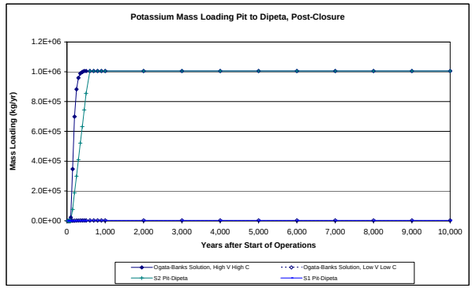
Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
2.67E+03	1.12E+02	1.26E+03	7.60E+00	1.51E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
4.37E+03	1.90E+02	2.06E+03	1.29E+01	3.75E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
4.37E+03	1.90E+02	2.06E+03	1.39E+01	3.75E+02	0.00E+00	1.34E-02	2.18E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5.59E+03	2.48E+02	2.40E+03	1.74E+01	5.50E+02	0.00E+00	2.03E-02	3.35E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7.49E+03	3.35E+02	3.21E+03	2.38E+01	7.78E+02	0.00E+00	2.72E-02	4.51E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9.39E+03	4.21E+02	4.02E+03	3.01E+01	1.01E+03	0.00E+00	3.41E-02	5.68E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.13E+04	5.07E+02	4.84E+03	3.65E+01	1.24E+03	0.00E+00	4.10E-02	6.84E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.32E+04	5.94E+02	5.65E+03	4.29E+01	1.46E+03	0.00E+00	4.78E-02	8.01E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.51E+04	6.80E+02	6.46E+03	4.92E+01	1.69E+03	0.00E+00	5.47E-02	9.18E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.70E+04	7.67E+02	7.28E+03	5.56E+01	1.92E+03	0.00E+00	6.16E-02	1.03E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.89E+04	8.53E+02	8.09E+03	6.20E+01	2.15E+03	0.00E+00	6.85E-02	1.15E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2.84E+04	1.29E+03	1.22E+04	9.38E+01	3.29E+03	0.00E+00	1.03E-01	1.73E-04	0.00E+00	0.00E+00	7.65E+04	9.32E+01	0.00E+00	0.00E+00
3.79E+04	1.72E+03	1.62E+04	1.26E+02	4.44E+03	0.00E+00	1.37E-01	2.32E-04	0.00E+00	0.00E+00	1.88E+05	2.75E+02	7.06E+02	1.02E+01
4.74E+04	2.16E+03	2.03E+04	1.58E+02	5.60E+03	0.00E+00	1.72E-01	2.90E-04	0.00E+00	0.00E+00	2.99E+05	4.57E+02	6.66E+03	9.66E+01
5.69E+04	2.58E+03	2.43E+04	1.89E+02	6.72E+03	0.00E+00	2.06E-01	3.48E-04	0.00E+00	0.00E+00	4.10E+05	6.39E+02	1.26E+04	1.83E+02
6.64E+04	3.01E+03	2.84E+04	2.21E+02	7.87E+03	0.00E+00	2.41E-01	4.06E-04	0.00E+00	0.00E+00	5.21E+05	8.21E+02	1.86E+04	2.69E+02
6.83E+04	3.45E+03	2.92E+04	2.53E+02	9.01E+03	0.00E+00	2.48E-01	4.65E-04	0.00E+00	0.00E+00	6.33E+05	1.00E+03	2.45E+04	3.56E+02
6.83E+04	3.88E+03	2.92E+04	2.85E+02	1.02E+04	0.00E+00	2.48E-01	5.23E-04	0.00E+00	0.00E+00	7.44E+05	1.18E+03	3.05E+04	4.42E+02
6.83E+04	4.31E+03	2.92E+04	3.17E+02	1.13E+04	0.00E+00	2.48E-01	5.81E-04	0.00E+00	0.00E+00	8.55E+05	1.37E+03	3.65E+04	5.29E+02
6.83E+04	5.17E+03	2.92E+04	3.81E+02	1.36E+04	0.00E+00	2.48E-01	6.98E-04	0.00E+00	0.00E+00	1.00E+06	1.73E+03	4.84E+04	7.01E+02
6.83E+04	6.04E+03	2.92E+04	4.44E+02	1.46E+04	0.00E+00	2.48E-01	8.14E-04	0.00E+00	0.00E+00	1.00E+06	2.09E+03	6.03E+04	8.74E+02
6.83E+04	6.65E+03	2.92E+04	5.08E+02	1.46E+04	0.00E+00	2.48E-01	8.97E-04	0.00E+00	0.00E+00	1.00E+06	2.46E+03	7.22E+04	1.05E+03
6.83E+04	6.65E+03	2.92E+04	5.72E+02	1.46E+04	0.00E+00	2.48E-01	8.97E-04	0.00E+00	0.00E+00	1.00E+06	2.57E+03	8.41E+04	1.22E+03
6.83E+04	6.65E+03	2.92E+04	6.35E+02	1.46E+04	0.00E+00	2.48E-01	8.97E-04	0.00E+00	0.00E+00	1.00E+06	2.57E+03	9.60E+04	1.39E+03
6.83E+04	6.65E+03	2.92E+04	1.22E+03	1.46E+04	0.00E+00	2.48E-01	8.97E-04	0.00E+00	0.00E+00	1.00E+06	2.57E+03	1.77E+05	2.57E+03
6.83E+04	6.65E+03	2.92E+04	1.22E+03	1.46E+04	0.00E+00	2.48E-01	8.97E-04	0.00E+00	0.00E+00	1.00E+06	2.57E+03	1.77E+05	2.57E+03
6.83E+04	6.65E+03	2.92E+04	1.22E+03	1.46E+04	0.00E+00	2.48E-01	8.97E-04	0.00E+00	0.00E+00	1.00E+06	2.57E+03	1.77E+05	2.57E+03
6.83E+04	6.65E+03	2.92E+04	1.22E+03	1.46E+04	0.00E+00	2.48E-01	8.97E-04	0.00E+00	0.00E+00	1.00E+06	2.57E+03	1.77E+05	2.57E+03
6.83E+04	6.65E+03	2.92E+04	1.22E+03	1.46E+04	0.00E+00	2.48E-01	8.97E-04	0.00E+00	0.00E+00	1.00E+06	2.57E+03	1.77E+05	2.57E+03
6.83E+04	6.65E+03	2.92E+04	1.22E+03	1.46E+04	0.00E+00	2.48E-01	8.97E-04	0.00E+00	0.00E+00	1.00E+06	2.57E+03	1.77E+05	2.57E+03
6.83E+04	6.65E+03	2.92E+04	1.22E+03	1.46E+04	0.00E+00	2.48E-01	8.97E-04	0.00E+00	0.00E+00	1.00E+06	2.57E+03	1.77E+05	2.57E+03

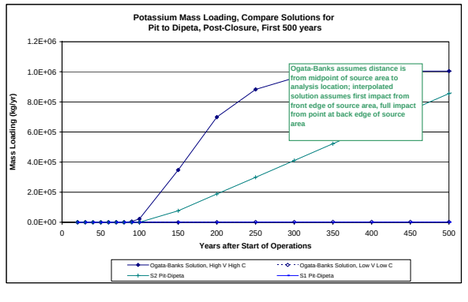
Ogata-Banks Solution, High V High C: Post-closure Loading to Dipeta, Scenario 1 (kg/yr)			Ogata-Banks Solution, Low V Low C: Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)	Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
5.01E+00	0.0	0.00E+00	6.46E+00	0.0	0.00E+00
3.22E+00	0.0	0.00E+00	4.31E+00	0.0	0.00E+00
2.36E+00	0.0	0.00E+00	3.31E+00	0.0	0.00E+00
1.82E+00	0.0	5.12E+03	2.68E+00	0.0	0.00E+00
1.42E+00	0.0	2.24E+04	2.24E+00	0.0	0.00E+00
2.80E-01	0.7	3.47E+05	1.00E+00	0.2	2.01E+02
-3.62E-01	1.4	6.99E+05	3.45E-01	0.6	8.03E+02
-8.25E-01	1.8	8.83E+05	-1.10E-01	1.1	1.44E+03
-1.20E+00	1.9	9.59E+05	-4.65E-01	1.5	1.91E+03
-1.51E+00	2.0	9.88E+05	-7.59E-01	1.7	2.20E+03
-1.78E+00	2.0	9.99E+05	-1.01E+00	1.8	2.37E+03
-2.03E+00	2.0	1.00E+06	-1.24E+00	1.9	2.46E+03
-2.26E+00	2.0	1.00E+06	-1.44E+00	2.0	2.51E+03
-2.66E+00	2.0	1.00E+06	-1.79E+00	2.0	2.55E+03
-3.01E+00	2.0	1.00E+06	-2.11E+00	2.0	2.57E+03
-3.33E+00	2.0	1.00E+06	-2.38E+00	2.0	2.57E+03
-3.63E+00	2.0	1.00E+06	-2.64E+00	2.0	2.57E+03
-3.90E+00	2.0	1.00E+06	-2.87E+00	2.0	2.57E+03
-6.00E+00	2.0	1.00E+06	-4.63E+00	2.0	2.57E+03
-7.54E+00	2.0	1.00E+06	-5.89E+00	2.0	2.57E+03
-8.82E+00	2.0	1.00E+06	-6.94E+00	2.0	2.57E+03
-9.94E+00	2.0	1.00E+06	-7.84E+00	2.0	2.57E+03
-1.09E+01	2.0	1.00E+06	-8.65E+00	2.0	2.57E+03
-1.19E+01	2.0	1.00E+06	-9.40E+00	2.0	2.57E+03
-1.27E+01	2.0	1.00E+06	-1.01E+01	2.0	2.57E+03
-1.35E+01	2.0	1.00E+06	-1.07E+01	2.0	2.57E+03
-1.43E+01	2.0	1.00E+06	-1.13E+01	2.0	2.57E+03

* End of operational period: 16 years









DATA SHEET 25 - sodium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	11		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	1	1
	1	771	360
Ore Stockpile East	0	3	1
	1	1,924	359
Ore Stockpile Southwest	0	N/A	6
	1	N/A	643
Tailings Facility	0	1	1
	1	771	360
ROM Ore Stockpiles	0	N/A	68
	1	N/A	836
Pit to Dipeta	0	66	74
	1	517	780
Pit to Mofia	0	N/A	144
	1	N/A	1,630

Transport Parameters

Kasana Waste Rock

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	21.5477989	464.307636	1.27120503	
	b	9.15	13.40	Scenario 2	14.7199489	216.676897	0.59322901	
	c	-210.8	-210.8					
Full Contribu	a	0.03	0.06	Scenario 1	530.69	281,630	771	
	b	-9.15	-13.40	Scenario 2	362.53	131,428	360	
	c	-3372.8	-3372.8					

Ore Stockpile East

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	31.383198	985	3	
	b	6.32	14.62	Scenario 2	13.5590912	184	1	
	c	-210.8	-210.8					
Full Contribu	a	0.01	0.07	Scenario 1	838.21	702,589	1,924	
	b	-6.32	-14.62	Scenario 2	362.15	131,150	359	
	c	-3689	-3689					

Ore Stockpile Southwest

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A	
	b	N/A	14.61	Scenario 2	46.6880345	2,180	6	
	c	-790.5	-790.5					
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A	
	b	N/A	-14.61	Scenario 2	484.748672	234,981	643	
	c	-4584.9	-4584.9					

Tailings Facility

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	21.5478	464	1	
	b	9.15	13.40	Scenario 2	14.71995	217	1	
	c	-210.8	-210.8					
Full Contrib	a	0.03	0.06	Scenario 1	530.6887	281,630	771	
	b	-9.15	-13.40	Scenario 2	362.5294	131,428	360	
	c	-3372.8	-3372.8					

ROM Ore Stockpiles

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A	
	b	N/A	18.87	Scenario 2	157.8729	24,924	68	
	c	-4216	-4216					
Full Contrib	a	N/A	0.05	Scenario 1	N/A	N/A	N/A	
	b	N/A	-18.87	Scenario 2	552.7191	305,498	836	
	c	-4743	-4743					

Pit to Dipeta, Post-closure

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	75.51404	5,702	66	
	b	27.14	21.71	Scenario 2	94.39255	8,910	74	
	c	-2635	-2635					
Full Contrib	a	0.10	0.07	Scenario 1	413.12	170,668	517	
	b	-27.14	-21.71	Scenario 2	516.40	266,668	780	
	c	-6324	-6324					

Pit to Mofia, Post-closure

		Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A	
	b	N/A	20.81	Scenario 2	185.367	34,361	144	
	c	-5270	-5270					
Full Contrib	a	N/A	0.04	Scenario 1	N/A	N/A	N/A	
	b	-27.14	-20.81	Scenario 2	759.65	577,065	1,630	
	c	-7905	-7905					

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

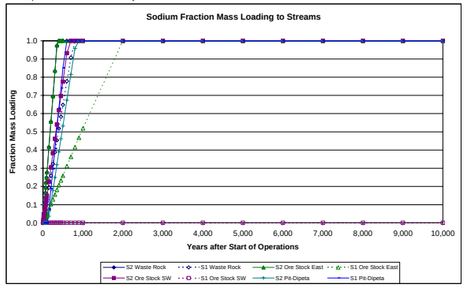
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	1.13E-02	3.80E-03	0.00E+00	1.13E-02	0.00E+00			2.62E-02	2.65E-02	6.33E-03	2.62E-02	0.00E+00		
16	1.91E-02	6.93E-03	0.00E+00	1.91E-02	0.00E+00			4.29E-02	4.32E-02	1.57E-02	4.29E-02	0.00E+00		
20	2.43E-02	9.01E-03	0.00E+00	2.43E-02	0.00E+00	0.00E+00	0.00E+00	5.40E-02	5.44E-02	2.20E-02	5.40E-02	0.00E+00	0.00E+00	0.00E+00
30	3.73E-02	1.42E-02	0.00E+00	3.73E-02	0.00E+00	0.00E+00	0.00E+00	8.19E-02	8.23E-02	3.77E-02	8.19E-02	0.00E+00	0.00E+00	0.00E+00
40	5.03E-02	1.94E-02	0.00E+00	5.03E-02	0.00E+00	0.00E+00	0.00E+00	1.10E-01	1.10E-01	5.34E-02	1.10E-01	0.00E+00	0.00E+00	0.00E+00
50	6.33E-02	2.46E-02	0.00E+00	6.33E-02	0.00E+00	0.00E+00	0.00E+00	1.38E-01	1.38E-01	6.91E-02	1.38E-01	0.00E+00	0.00E+00	0.00E+00
60	7.63E-02	2.98E-02	0.00E+00	7.63E-02	0.00E+00	0.00E+00	0.00E+00	1.65E-01	1.66E-01	8.48E-02	1.65E-01	0.00E+00	0.00E+00	0.00E+00
70	8.93E-02	3.50E-02	0.00E+00	8.93E-02	0.00E+00	0.00E+00	0.00E+00	1.93E-01	1.94E-01	1.00E-01	1.93E-01	2.29E-03	0.00E+00	0.00E+00
80	1.02E-01	4.02E-02	0.00E+00	1.02E-01	0.00E+00	0.00E+00	0.00E+00	2.21E-01	2.22E-01	1.16E-01	2.21E-01	1.53E-02	0.00E+00	0.00E+00
90	1.15E-01	4.54E-02	0.00E+00	1.15E-01	0.00E+00	0.00E+00	0.00E+00	2.49E-01	2.50E-01	1.32E-01	2.49E-01	2.83E-02	0.00E+00	0.00E+00
100	1.28E-01	5.07E-02	0.00E+00	1.28E-01	0.00E+00	0.00E+00	0.00E+00	2.77E-01	2.77E-01	1.48E-01	2.77E-01	4.13E-02	0.00E+00	0.00E+00
150	1.93E-01	7.67E-02	0.00E+00	1.93E-01	0.00E+00	7.61E-02	0.00E+00	4.16E-01	4.17E-01	2.26E-01	4.16E-01	1.06E-01	3.63E-02	0.00E+00
200	2.58E-01	1.03E-01	0.00E+00	2.58E-01	0.00E+00	1.87E-01	0.00E+00	5.55E-01	5.56E-01	3.04E-01	5.55E-01	1.72E-01	1.07E-01	3.99E-03
250	3.23E-01	1.29E-01	0.00E+00	3.23E-01	0.00E+00	2.98E-01	0.00E+00	6.94E-01	6.94E-01	3.84E-01	6.94E-01	2.37E-01	1.78E-01	3.76E-02
300	3.88E-01	1.55E-01	0.00E+00	3.88E-01	0.00E+00	4.08E-01	0.00E+00	8.33E-01	8.35E-01	4.61E-01	8.33E-01	3.02E-01	2.49E-01	7.13E-02
350	4.53E-01	1.81E-01	0.00E+00	4.53E-01	0.00E+00	5.19E-01	0.00E+00	9.73E-01	9.75E-01	5.40E-01	9.73E-01	3.67E-01	3.20E-01	1.05E-01
400	5.18E-01	2.07E-01	0.00E+00	5.18E-01	0.00E+00	6.30E-01	0.00E+00	1.00E+00	1.00E+00	6.18E-01	1.00E+00	4.32E-01	3.91E-01	1.39E-01
450	5.83E-01	2.33E-01	0.00E+00	5.83E-01	0.00E+00	7.40E-01	0.00E+00	1.00E+00	1.00E+00	6.97E-01	1.00E+00	4.97E-01	4.61E-01	1.72E-01
500	6.48E-01	2.59E-01	0.00E+00	6.48E-01	0.00E+00	8.51E-01	0.00E+00	1.00E+00	1.00E+00	7.75E-01	1.00E+00	5.62E-01	5.32E-01	2.06E-01
600	7.78E-01	3.11E-01	0.00E+00	7.78E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	9.32E-01	1.00E+00	6.92E-01	6.74E-01	2.73E-01
700	9.08E-01	3.63E-01	0.00E+00	9.08E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	8.22E-01	8.16E-01	3.40E-01
800	1.00E+00	4.15E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.53E-01	9.57E-01	4.08E-01
900	1.00E+00	4.67E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.75E-01
1,000	1.00E+00	5.19E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	5.42E-01
2,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
3,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
4,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
5,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
6,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
7,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
8,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
9,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
10,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00

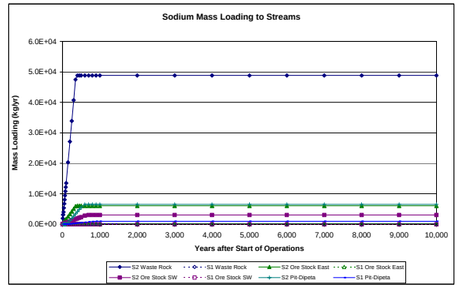
Loading Calculations to Kasana (kg/year)

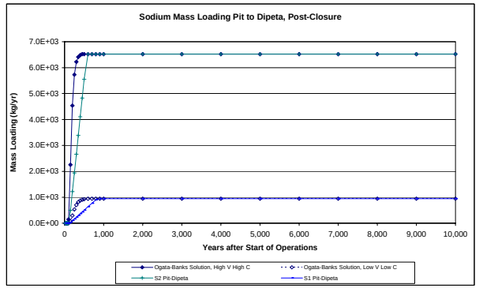
	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	1.91E+03	7.16E-01	2.62E+02	3.31E-01	3.13E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	3.12E+03	1.21E+00	4.27E+02	6.03E-01	7.78E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	3.12E+03	1.21E+00	4.27E+02	6.03E-01	7.78E+01	0.00E+00	6.88E-03	3.10E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	4.00E+03	1.58E+00	4.98E+02	7.57E-01	1.14E+02	0.00E+00	1.04E-02	4.75E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	5.36E+03	2.13E+00	6.66E+02	1.03E+00	1.61E+02	0.00E+00	1.40E-02	6.40E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	6.72E+03	2.68E+00	8.35E+02	1.31E+00	2.09E+02	0.00E+00	1.75E-02	8.06E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	8.07E+03	3.23E+00	1.00E+03	1.59E+00	2.56E+02	0.00E+00	2.10E-02	9.71E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	9.43E+03	3.78E+00	1.17E+03	1.87E+00	3.04E+02	0.00E+00	2.46E-02	1.14E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	1.08E+04	4.33E+00	1.34E+03	2.14E+00	3.51E+02	0.00E+00	2.81E-02	1.30E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	1.22E+04	4.88E+00	1.51E+03	2.42E+00	3.99E+02	0.00E+00	3.17E-02	1.47E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	1.35E+04	5.43E+00	1.68E+03	2.70E+00	4.46E+02	0.00E+00	3.52E-02	1.63E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	2.03E+04	8.18E+00	2.52E+03	4.08E+00	6.84E+02	0.00E+00	5.29E-02	2.46E-04	0.00E+00	0.00E+00	4.96E+02	3.43E+01	0.00E+00	0.00E+00
200	2.71E+04	1.09E+01	3.37E+03	5.47E+00	9.21E+02	0.00E+00	7.07E-02	3.29E-04	0.00E+00	0.00E+00	1.22E+03	1.01E+02	4.58E+00	3.77E+00
250	3.39E+04	1.37E+01	4.21E+03	6.86E+00	8.84E+02	4.11E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.94E+03	1.68E+02	4.32E+01	3.56E+01
300	4.07E+04	1.64E+01	5.05E+03	8.24E+00	1.40E+03	0.00E+00	1.06E-01	4.94E-04	0.00E+00	0.00E+00	2.66E+03	2.35E+02	8.19E+01	6.74E+01
350	4.75E+04	1.92E+01	5.90E+03	9.63E+00	1.63E+03	0.00E+00	1.24E-01	5.77E-04	0.00E+00	0.00E+00	3.38E+03	3.02E+02	1.21E+02	9.93E+01
400	4.88E+04	2.19E+01	6.05E+03	1.10E+01	1.87E+03	0.00E+00	1.42E-01	6.59E-04	0.00E+00	0.00E+00	4.11E+03	3.69E+02	1.59E+02	1.31E+02
450	4.88E+04	2.47E+01	6.05E+03	1.24E+01	2.11E+03	0.00E+00	1.60E-01	7.42E-04	0.00E+00	0.00E+00	4.83E+03	4.36E+02	1.98E+02	1.63E+02
500	4.88E+04	2.74E+01	6.05E+03	1.38E+01	2.34E+03	0.00E+00	1.77E-01	8.25E-04	0.00E+00	0.00E+00	5.55E+03	5.04E+02	2.37E+02	1.95E+02
600	4.88E+04	3.29E+01	6.05E+03	1.66E+01	2.82E+03	0.00E+00	1.27E-01	9.90E-04	0.00E+00	0.00E+00	6.52E+03	6.38E+02	3.14E+02	2.58E+02
700	4.88E+04	3.85E+01	6.05E+03	1.93E+01	3.02E+03	0.00E+00	1.27E-01	1.16E-03	0.00E+00	0.00E+00	6.52E+03	7.72E+02	3.91E+02	3.22E+02
800	4.88E+04	4.24E+01	6.05E+03	2.21E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.06E+02	4.68E+02	3.86E+02
900	4.88E+04	4.24E+01	6.05E+03	2.49E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.46E+02	5.46E+02	4.49E+02
1,000	4.88E+04	4.24E+01	6.05E+03	2.76E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.46E+02	6.23E+02	5.13E+02
2,000	4.88E+04	4.24E+01	6.05E+03	5.32E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.46E+02	1.15E+03	9.46E+02
3,000	4.88E+04	4.24E+01	6.05E+03	5.32E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.46E+02	1.15E+03	9.46E+02
4,000	4.88E+04	4.24E+01	6.05E+03	5.32E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.46E+02	1.15E+03	9.46E+02
5,000	4.88E+04	4.24E+01	6.05E+03	5.32E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.46E+02	1.15E+03	9.46E+02
6,000	4.88E+04	4.24E+01	6.05E+03	5.32E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.46E+02	1.15E+03	9.46E+02
7,000	4.88E+04	4.24E+01	6.05E+03	5.32E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.46E+02	1.15E+03	9.46E+02
8,000	4.88E+04	4.24E+01	6.05E+03	5.32E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.46E+02	1.15E+03	9.46E+02
9,000	4.88E+04	4.24E+01	6.05E+03	5.32E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.46E+02	1.15E+03	9.46E+02
10,000	4.88E+04	4.24E+01	6.05E+03	5.32E+01	3.02E+03	0.00E+00	1.27E-01	1.27E-03	0.00E+00	0.00E+00	6.52E+03	9.46E+02	1.15E+03	9.46E+02

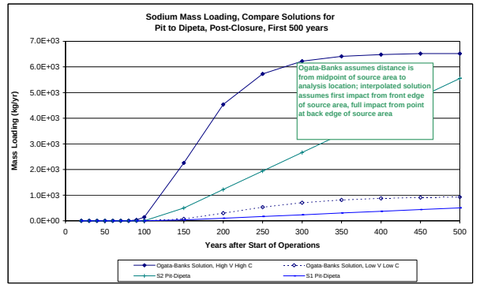
* End of operational period: 16 years

Ogata-Banks Solution, High V High C			Ogata-Banks Solution, Low V Low C		
Post-closure Loading to Dipeta, Scenario 1 (kg/yr)			Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)	Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
5.01E+00	0.0	0.00E+00	6.46E+00	0.0	0.00E+00
3.22E+00	0.0	0.00E+00	4.31E+00	0.0	0.00E+00
2.36E+00	0.0	0.00E+00	3.31E+00	0.0	0.00E+00
1.82E+00	0.0	3.32E+01	2.68E+00	0.0	0.00E+00
1.42E+00	0.0	1.45E+02	2.24E+00	0.0	0.00E+00
2.80E-01	0.7	2.25E+03	1.00E+00	0.2	7.40E+01
-3.62E-01	1.4	4.54E+03	3.45E-01	0.6	2.96E+02
-8.25E-01	1.8	5.73E+03	-1.10E-01	1.1	5.32E+02
-1.20E+00	1.9	6.22E+03	-4.65E-01	1.5	7.04E+02
-1.51E+00	2.0	6.41E+03	-7.59E-01	1.7	8.12E+02
-1.78E+00	2.0	6.48E+03	-1.01E+00	1.8	8.74E+02
-2.03E+00	2.0	6.52E+03	-1.24E+00	1.9	9.08E+02
-2.26E+00	2.0	6.52E+03	-1.44E+00	2.0	9.26E+02
-2.66E+00	2.0	6.52E+03	-1.79E+00	2.0	9.41E+02
-3.01E+00	2.0	6.52E+03	-2.11E+00	2.0	9.46E+02
-3.33E+00	2.0	6.52E+03	-2.38E+00	2.0	9.46E+02
-3.63E+00	2.0	6.52E+03	-2.64E+00	2.0	9.46E+02
-3.90E+00	2.0	6.52E+03	-2.87E+00	2.0	9.46E+02
-6.00E+00	2.0	6.52E+03	-4.63E+00	2.0	9.46E+02
-7.54E+00	2.0	6.52E+03	-5.89E+00	2.0	9.46E+02
-8.82E+00	2.0	6.52E+03	-6.94E+00	2.0	9.46E+02
-9.94E+00	2.0	6.52E+03	-7.84E+00	2.0	9.46E+02
-1.09E+01	2.0	6.52E+03	-8.65E+00	2.0	9.46E+02
-1.19E+01	2.0	6.52E+03	-9.40E+00	2.0	9.46E+02
-1.27E+01	2.0	6.52E+03	-1.01E+01	2.0	9.46E+02
-1.35E+01	2.0	6.52E+03	-1.07E+01	2.0	9.46E+02
-1.43E+01	2.0	6.52E+03	-1.13E+01	2.0	9.46E+02









DATA SHEET 26 - nitrate

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	1		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

Assumes that nitrate loading to the groundwater only occurs for 20 years

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	0	0
	1	73	34
Ore Stockpile East	0	0	0
	1	183	34
Ore Stockpile Southwest	0	N/A	1
	1	N/A	61
Tailings Facility	0	0	0
	1	73	34
ROM Ore Stockpiles	0	N/A	6
	1	N/A	79
Pit to Dipeta	0	51	52
	1	94	119
Pit to Mofia	0	N/A	59
	1	N/A	200

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	6.6371649	44.0519579	0.12060769
	b	2.82	4.13	Scenario 2	4.5340468	20.5575804	0.05628359
	c	-20	-20				
Full Contribu	a	0.03	0.06	Scenario 1	163.46	26,720	73
	b	-2.82	-4.13	Scenario 2	111.67	12,469	34
	c	-320	-320				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	9.66666996	93	0
	b	1.95	4.50	Scenario 2	4.17647876	17	0
	c	-20	-20				
Full Contribu	a	0.01	0.07	Scenario 1	258.18	66,659	183
	b	-1.95	-4.50	Scenario 2	111.55	12,443	34
	c	-350	-350				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	4.50	Scenario 2	14.3808742	207	1
	c	-75	-75				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-4.50	Scenario 2	149.312553	22,294	61
	c	-435	-435				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	6.637165	44	0
	b	2.82	4.13	Scenario 2	4.534047	21	0
	c	-20	-20				
Full Contribu	a	0.03	0.06	Scenario 1	163.463	26,720	73
	b	-2.82	-4.13	Scenario 2	111.6665	12,469	34
	c	-320	-320				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	5.81	Scenario 2	48.62808	2,365	6
	c	-400	-400				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-5.81	Scenario 2	170.2489	28,985	79
	c	-450	-450				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	23.25988	541	51
	b	8.36	6.69	Scenario 2	29.07484	845	52
	c	-250	-250				
Full Contribu	a	0.10	0.07	Scenario 1	127.25	16,192	94
	b	-8.36	-6.69	Scenario 2	159.06	25,301	119
	c	-600	-600				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	6.41	Scenario 2	57.09683	3,260	59
	c	-500	-500				
Full Contrib	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-8.36	-6.41	Scenario 2	233.99	54,750	200
	c	-750	-750				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading	Loading Calculations to Kasana (kg/year): Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	1.35E-01	5.35E-02	0.00E+00	1.35E-01	0.00E+00			2.92E-01	2.93E-01	1.56E-01	2.92E-01	4.84E-02			1.44E+03	6.66E+02	6.03E+02	1.10E+02	1.61E+02	0.00E+00	0.00E+00	0.00E+00	7.42E+00	0.00E+00				
16	2.17E-01	8.64E-02	0.00E+00	2.17E-01	0.00E+00			4.68E-01	4.69E-01	2.55E-01	4.68E-01	1.31E-01			2.30E+03	1.07E+03	9.66E+02	1.78E+02	2.63E+02	0.00E+00	0.00E+00	0.00E+00	2.01E+01	0.00E+00				
20	2.72E-01	1.08E-01	0.00E+00	2.72E-01	0.00E+00	0.00E+00	0.00E+00	5.85E-01	5.86E-01	3.21E-01	5.85E-01	1.86E-01	0.00E+00	0.00E+00	1.93E+03	8.98E+02	7.39E+02	1.37E+02	2.03E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	2.74E-01	1.10E-01	0.00E+00	2.74E-01	0.00E+00	0.00E+00	0.00E+00	5.87E-01	5.88E-01	3.31E-01	5.87E-01	2.74E-01	0.00E+00	0.00E+00	1.94E+03	9.04E+02	7.41E+02	1.38E+02	2.09E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	2.74E-01	1.10E-01	0.00E+00	2.74E-01	0.00E+00	0.00E+00	0.00E+00	4.15E-01	4.14E-01	3.31E-01	4.15E-01	2.74E-01	0.00E+00	0.00E+00	1.37E+03	9.04E+02	5.21E+02	1.38E+02	2.09E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	2.74E-01	1.10E-01	0.00E+00	2.74E-01	0.00E+00	0.00E+00	0.00E+00	1.21E-01	1.20E-01	3.31E-01	1.21E-01	2.74E-01	0.00E+00	0.00E+00	4.01E+02	9.04E+02	1.51E+02	1.38E+02	2.09E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	2.74E-01	1.10E-01	0.00E+00	2.74E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.31E-01	0.00E+00	2.74E-01	0.00E+00	0.00E+00	0.00E+00	9.04E+02	0.00E+00	1.38E+02	2.09E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	2.74E-01	1.10E-01	0.00E+00	2.74E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-01	0.00E+00	2.74E-01	0.00E+00	0.00E+00	0.00E+00	9.04E+02	0.00E+00	1.38E+02	1.15E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	1.80E-01	1.10E-01	0.00E+00	1.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.72E-02	0.00E+00	2.66E-01	0.00E+00	0.00E+00	0.00E+00	5.95E+02	0.00E+00	1.38E+02	1.08E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	4.32E-02	1.10E-01	0.00E+00	4.32E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E-01	0.00E+00	0.00E+00	0.00E+00	1.43E+02	0.00E+00	1.38E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	1.10E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	1.10E-01	0.00E+00	0.00E+00	0.00E+00	3.34E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.99E-01	1.42E-01	0.00E+00	0.00E+00	0.00E+00	1.38E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.67E+04	2.62E+03	1.25E+03	1.25E+03
200	0.00E+00	1.37E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-01	0.00E+00	0.00E+00	0.00E+00	1.73E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E+03	1.25E+03
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.41E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E+03	1.24E+03
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
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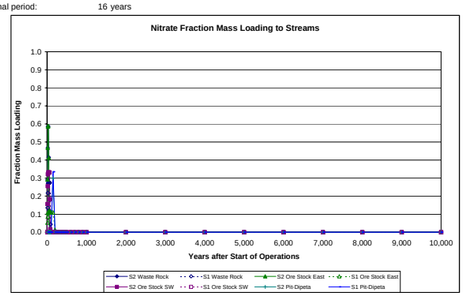
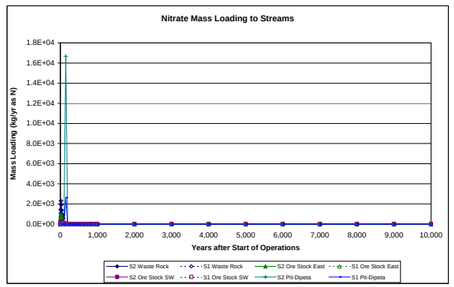
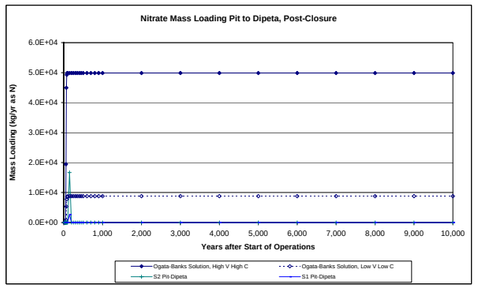
8,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

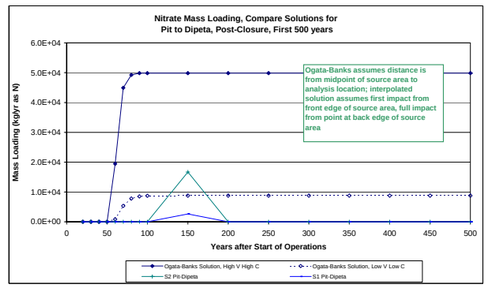
Ogata-Banks Solution, High V High C			Ogata-Banks Solution, Low V Low C		
Post-closure Loading to Dipeta, Scenario 1 (kg/yr)			Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)	Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
1.97E-01	0.8	1.95E+04	9.15E-01	0.2	8.59E+02
-9.12E-01	1.8	4.49E+04	-1.94E-01	1.2	5.34E+03
-1.60E+00	2.0	4.93E+04	-8.45E-01	1.8	7.76E+03
-2.13E+00	2.0	4.99E+04	-1.33E+00	1.9	8.52E+03
-2.57E+00	2.0	4.99E+04	-1.72E+00	2.0	8.72E+03
-4.17E+00	2.0	4.99E+04	-3.09E+00	2.0	8.78E+03
-5.32E+00	2.0	4.99E+04	-4.06E+00	2.0	8.78E+03
-6.27E+00	2.0	4.99E+04	-4.85E+00	2.0	8.78E+03
-7.09E+00	2.0	4.99E+04	-5.52E+00	2.0	8.78E+03
-7.83E+00	2.0	4.99E+04	-6.13E+00	2.0	8.78E+03
-8.51E+00	2.0	4.99E+04	-6.68E+00	2.0	8.78E+03
-9.13E+00	2.0	4.99E+04	-7.19E+00	2.0	8.78E+03
-9.72E+00	2.0	4.99E+04	-7.66E+00	2.0	8.78E+03
-1.08E+01	2.0	4.99E+04	-8.53E+00	2.0	8.78E+03
-1.18E+01	2.0	4.99E+04	-9.32E+00	2.0	8.78E+03
-1.27E+01	2.0	4.99E+04	-1.01E+01	2.0	8.78E+03
-1.35E+01	2.0	4.99E+04	-1.07E+01	2.0	8.78E+03
-1.43E+01	2.0	4.99E+04	-1.14E+01	2.0	8.78E+03
-2.06E+01	2.0	4.99E+04	-1.65E+01	2.0	8.78E+03
-2.54E+01	2.0	4.99E+04	-2.03E+01	2.0	8.78E+03
-2.95E+01	2.0	4.99E+04	-2.35E+01	2.0	8.78E+03
-3.30E+01	2.0	4.99E+04	-2.64E+01	2.0	8.78E+03
-3.62E+01	2.0	4.99E+04	-2.89E+01	2.0	8.78E+03
-3.91E+01	2.0	4.99E+04	-3.13E+01	2.0	8.78E+03
-4.18E+01	2.0	4.99E+04	-3.34E+01	2.0	8.78E+03
-4.44E+01	2.0	4.99E+04	-3.55E+01	2.0	8.78E+03
-4.68E+01	2.0	4.99E+04	-3.74E+01	2.0	8.78E+03

* End of operational period: 16 years









DATA SHEET 27 - phosphorus

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	2386		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation **16**
Years to Pit Flow-Through **50**

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	288	134
	1	174,550	81,457
Ore Stockpile East	0	610	114
	1	435,453	81,285
Ore Stockpile Southwest	0	N/A	1,351
	1	N/A	145,637
Tailings Facility	0	288	134
	1	174,550	81,457
ROM Ore Stockpiles	0	N/A	15,447
	1	N/A	189,343
Pit to Dipeta	0	3,584	5,572
	1	105,827	165,327
Pit to Mofia	0	N/A	21,346
	1	N/A	357,705

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	324.203596	105107.972	287.769943
	b	137.72	201.60	Scenario 2	221.473219	49050.3867	134.29264
	c	-47720	-47720				
Full Contribu	a	0.03	0.06	Scenario 1	7984.63	63,754,296	174,550
	b	-137.72	-201.60	Scenario 2	5454.54	29,752,005	81,457
	c	-763520	-763520				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	472.184917	222,959	610
	b	95.03	219.94	Scenario 2	204.007201	41,619	114
	c	-47720	-47720				
Full Contribu	a	0.01	0.07	Scenario 1	12611.47	#########	435,453
	b	-95.03	-219.94	Scenario 2	5448.78	29,689,178	81,285
	c	-835100	-835100				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	219.87	Scenario 2	702.458231	493,448	1,351
	c	-178950	-178950				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-219.87	Scenario 2	7293.42535	53,194,053	145,637
	c	-1037910	-1037910				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	324.2036	105,108	288
	b	137.72	201.60	Scenario 2	221.4732	49,050	134
	c	-47720	-47720				
Full Contribu	a	0.03	0.06	Scenario 1	7984.629	63,754,296	174,550
	b	-137.72	-201.60	Scenario 2	5454.54	29,752,005	81,457
	c	-763520	-763520				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	283.85	Scenario 2	2375.321	5,642,152	15,447
	c	-954400	-954400				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-283.85	Scenario 2	8316.094	69,157,426	189,343
	c	-1073700	-1073700				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	1136.168	1,290,878	3,584
	b	408.28	326.62	Scenario 2	1420.21	2,016,997	5,572
	c	-596500	-596500				
Full Contribu	a	0.10	0.07	Scenario 1	6215.71	38,635,052	105,827
	b	-408.28	-326.62	Scenario 2	7769.64	60,367,268	165,327
	c	-1431600	-1431600				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	313.14	Scenario 2	2788.992	7,778,476	21,346
	c	-1193000	-1193000				
Full Contribu	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-408.28	-313.14	Scenario 2	11429.50	130,633,500	357,705
	c	-1789500	-1789500				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Scenario 1

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	7.02E-05	0.00E+00	0.00E+00	7.02E-05	0.00E+00	0.00E+00	0.00E+00
350	3.57E-04	0.00E+00	0.00E+00	3.57E-04	0.00E+00	0.00E+00	0.00E+00
400	6.44E-04	0.00E+00	0.00E+00	6.44E-04	0.00E+00	0.00E+00	0.00E+00
450	9.31E-04	0.00E+00	0.00E+00	9.31E-04	0.00E+00	0.00E+00	0.00E+00
500	1.22E-03	0.00E+00	0.00E+00	1.22E-03	0.00E+00	0.00E+00	0.00E+00
600	1.79E-03	0.00E+00	0.00E+00	1.79E-03	0.00E+00	0.00E+00	0.00E+00
700	2.37E-03	2.06E-04	0.00E+00	2.37E-03	0.00E+00	0.00E+00	0.00E+00
800	2.94E-03	4.36E-04	0.00E+00	2.94E-03	0.00E+00	0.00E+00	0.00E+00
900	3.51E-03	6.66E-04	0.00E+00	3.51E-03	0.00E+00	0.00E+00	0.00E+00
1,000	4.09E-03	8.96E-04	0.00E+00	4.09E-03	0.00E+00	0.00E+00	0.00E+00
2,000	9.83E-03	3.20E-03	0.00E+00	9.83E-03	0.00E+00	0.00E+00	0.00E+00
3,000	1.56E-02	5.50E-03	0.00E+00	1.56E-02	0.00E+00	0.00E+00	0.00E+00
4,000	2.13E-02	7.79E-03	0.00E+00	2.13E-02	0.00E+00	3.58E-03	0.00E+00
5,000	2.70E-02	1.01E-02	0.00E+00	2.70E-02	0.00E+00	1.34E-02	0.00E+00
6,000	3.28E-02	1.24E-02	0.00E+00	3.28E-02	0.00E+00	2.31E-02	0.00E+00
7,000	3.85E-02	1.47E-02	0.00E+00	3.85E-02	0.00E+00	3.29E-02	0.00E+00
8,000	4.43E-02	1.70E-02	0.00E+00	4.43E-02	0.00E+00	4.27E-02	0.00E+00
9,000	5.00E-02	1.93E-02	0.00E+00	5.00E-02	0.00E+00	5.25E-02	0.00E+00
10,000	5.57E-02	2.16E-02	0.00E+00	5.57E-02	0.00E+00	6.23E-02	0.00E+00

Scenario 2

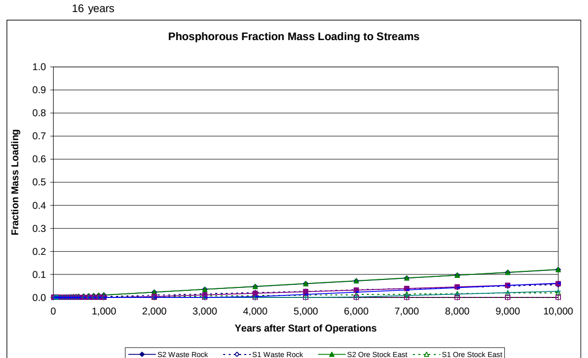
Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	1.93E-04	4.44E-04	0.00E+00	1.93E-04	0.00E+00	0.00E+00	0.00E+00
200	8.08E-04	1.06E-03	0.00E+00	8.08E-04	0.00E+00	0.00E+00	0.00E+00
250	1.42E-03	1.68E-03	0.00E+00	1.42E-03	0.00E+00	0.00E+00	0.00E+00
300	2.04E-03	2.29E-03	0.00E+00	2.04E-03	0.00E+00	0.00E+00	0.00E+00
350	2.65E-03	2.91E-03	0.00E+00	2.65E-03	0.00E+00	0.00E+00	0.00E+00
400	3.27E-03	3.52E-03	0.00E+00	3.27E-03	0.00E+00	0.00E+00	0.00E+00
450	3.88E-03	4.14E-03	0.00E+00	3.88E-03	0.00E+00	0.00E+00	0.00E+00
500	4.50E-03	4.76E-03	0.00E+00	4.50E-03	0.00E+00	0.00E+00	0.00E+00
600	5.73E-03	5.99E-03	0.00E+00	5.73E-03	0.00E+00	0.00E+00	0.00E+00
700	6.96E-03	7.22E-03	0.00E+00	6.96E-03	0.00E+00	0.00E+00	0.00E+00
800	8.19E-03	8.45E-03	0.00E+00	8.19E-03	0.00E+00	0.00E+00	0.00E+00
900	9.42E-03	9.68E-03	0.00E+00	9.42E-03	0.00E+00	0.00E+00	0.00E+00
1,000	1.06E-02	1.09E-02	0.00E+00	1.06E-02	0.00E+00	0.00E+00	0.00E+00
2,000	2.29E-02	2.32E-02	4.50E-03	2.29E-02	0.00E+00	0.00E+00	0.00E+00
3,000	3.52E-02	3.56E-02	1.14E-02	3.52E-02	0.00E+00	0.00E+00	0.00E+00
4,000	4.75E-02	4.79E-02	1.84E-02	4.75E-02	0.00E+00	0.00E+00	0.00E+00
5,000	5.98E-02	6.02E-02	2.53E-02	5.98E-02	0.00E+00	0.00E+00	0.00E+00
6,000	7.21E-02	7.25E-02	3.22E-02	7.21E-02	0.00E+00	2.36E-03	0.00E+00
7,000	8.44E-02	8.48E-02	3.92E-02	8.44E-02	0.00E+00	8.62E-03	0.00E+00
8,000	9.67E-02	9.72E-02	4.61E-02	9.67E-02	0.00E+00	1.49E-02	0.00E+00
9,000	1.09E-01	1.09E-01	5.30E-02	1.09E-01	0.00E+00	2.11E-02	0.00E+00
10,000	1.21E-01	1.22E-01	5.99E-02	1.21E-01	0.00E+00	2.74E-02	0.00E+00

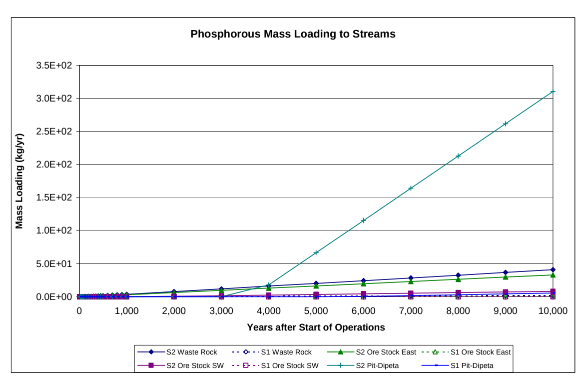
Loading Calculations to Kasana (kg/year)

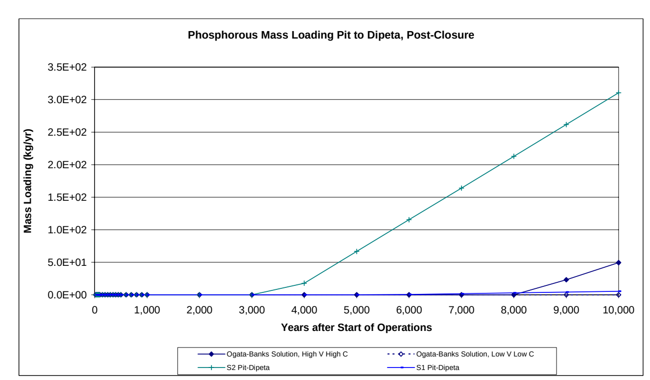
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	6.51E-02	0.00E+00	1.20E-01	0.00E+00	0.00E+00	0.00E+00	1.55E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	2.72E-01	0.00E+00	2.87E-01	0.00E+00	0.00E+00	0.00E+00	6.49E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	4.79E-01	0.00E+00	4.54E-01	0.00E+00	0.00E+00	0.00E+00	1.14E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	6.87E-01	2.36E-03	6.21E-01	0.00E+00	0.00E+00	0.00E+00	1.64E-06	6.28E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	8.94E-01	1.20E-02	7.88E-01	0.00E+00	0.00E+00	0.00E+00	2.13E-06	3.19E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	1.10E+00	2.17E-02	9.54E-01	0.00E+00	0.00E+00	0.00E+00	2.63E-06	5.76E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	1.31E+00	3.14E-02	1.12E+00	0.00E+00	0.00E+00	0.00E+00	3.12E-06	8.33E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	1.52E+00	4.10E-02	1.29E+00	0.00E+00	0.00E+00	0.00E+00	3.61E-06	1.09E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	1.93E+00	6.04E-02	1.62E+00	0.00E+00	0.00E+00	0.00E+00	4.60E-06	1.60E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	2.34E+00	7.97E-02	1.96E+00	4.15E-03	0.00E+00	0.00E+00	5.59E-06	2.12E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	2.76E+00	9.90E-02	2.29E+00	8.78E-03	0.00E+00	0.00E+00	6.58E-06	2.63E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	3.17E+00	1.18E-01	2.62E+00	1.34E-02	0.00E+00	0.00E+00	7.57E-06	3.14E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	3.59E+00	1.38E-01	2.96E+00	1.80E-02	0.00E+00	0.00E+00	8.56E-06	3.66E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	7.73E+00	3.31E-01	6.29E+00	6.44E-02	6.09E-01	0.00E+00	1.84E-05	8.79E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	1.19E+01	5.24E-01	9.63E+00	1.11E-01	1.55E+00	0.00E+00	2.83E-05	1.39E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	1.60E+01	7.18E-01	1.30E+01	1.57E-01	2.49E+00	0.00E+00	3.82E-05	1.91E-07	0.00E+00	0.00E+00	1.78E+01	0.00E+00	0.00E+00	0.00E+00
5,000	2.02E+01	9.11E-01	1.63E+01	2.03E-01	3.42E+00	0.00E+00	4.81E-05	2.42E-07	0.00E+00	0.00E+00	6.66E+01	0.00E+00	0.00E+00	0.00E+00
6,000	2.43E+01	1.10E+00	1.96E+01	2.50E-01	4.36E+00	0.00E+00	5.80E-05	2.93E-07	0.00E+00	0.00E+00	1.15E+02	4.79E-01	0.00E+00	0.00E+00
7,000	2.84E+01	1.30E+00	2.30E+01	2.96E-01	5.30E+00	0.00E+00	6.79E-05	3.45E-07	0.00E+00	0.00E+00	1.64E+02	1.75E+00	0.00E+00	0.00E+00
8,000	3.26E+01	1.49E+00	2.63E+01	3.42E-01	6.24E+00	0.00E+00	7.77E-05	3.96E-07	0.00E+00	0.00E+00	2.13E+02	3.02E+00	0.00E+00	0.00E+00
9,000	3.67E+01	1.68E+00	2.96E+01	3.89E-01	7.18E+00	0.00E+00	8.76E-05	4.47E-07	0.00E+00	0.00E+00	2.62E+02	4.29E+00	0.00E+00	0.00E+00
10,000	4.09E+01	1.88E+00	3.30E+01	4.35E-01	8.12E+00	0.00E+00	9.75E-05	4.99E-07	0.00E+00	0.00E+00	3.10E+02	5.55E+00	0.00E+00	0.00E+00

Time from Start of Operations (Years)*	Ogata-Banks Solution, High V High C — Post-closure Loading to Dipeta, Scenario 1 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)	Ogata-Banks Solution, Low V Low C — Post-closure Loading to Dipeta, Scenario 2 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)
0						
10						
16						
20	N/A	N/A	0	N/A	N/A	0
30	N/A	N/A	0	N/A	N/A	0
40	N/A	N/A	0	N/A	N/A	0
50	N/A	N/A	0	N/A	N/A	0
60	8.22E+01	0.0	0.00E+00	1.03E+02	0.0	0.00E+00
70	5.81E+01	0.0	0.00E+00	7.26E+01	0.0	0.00E+00
80	4.74E+01	0.0	0.00E+00	5.93E+01	0.0	0.00E+00
90	4.10E+01	0.0	0.00E+00	5.13E+01	0.0	0.00E+00
100	3.67E+01	0.0	0.00E+00	4.59E+01	0.0	0.00E+00
150	2.59E+01	0.0	0.00E+00	3.24E+01	0.0	0.00E+00
200	2.11E+01	0.0	0.00E+00	2.64E+01	0.0	0.00E+00
250	1.82E+01	0.0	0.00E+00	2.29E+01	0.0	0.00E+00
300	1.63E+01	0.0	0.00E+00	2.04E+01	0.0	0.00E+00
350	1.48E+01	0.0	0.00E+00	1.86E+01	0.0	0.00E+00
400	1.37E+01	0.0	0.00E+00	1.72E+01	0.0	0.00E+00
450	1.28E+01	0.0	0.00E+00	1.61E+01	0.0	0.00E+00
500	1.21E+01	0.0	0.00E+00	1.52E+01	0.0	0.00E+00
600	1.09E+01	0.0	0.00E+00	1.37E+01	0.0	0.00E+00
700	9.95E+00	0.0	0.00E+00	1.26E+01	0.0	0.00E+00
800	9.23E+00	0.0	0.00E+00	1.17E+01	0.0	0.00E+00
900	8.64E+00	0.0	0.00E+00	1.09E+01	0.0	0.00E+00
1,000	8.14E+00	0.0	0.00E+00	1.03E+01	0.0	0.00E+00
2,000	5.46E+00	0.0	0.00E+00	7.02E+00	0.0	0.00E+00
3,000	4.26E+00	0.0	0.00E+00	5.57E+00	0.0	0.00E+00
4,000	3.53E+00	0.0	0.00E+00	4.69E+00	0.0	0.00E+00
5,000	3.02E+00	0.0	0.00E+00	4.08E+00	0.0	0.00E+00
6,000	2.63E+00	0.0	0.00E+00	3.62E+00	0.0	0.00E+00
7,000	2.32E+00	0.0	0.00E+00	3.26E+00	0.0	0.00E+00
8,000	2.06E+00	0.0	0.00E+00	2.96E+00	0.0	0.00E+00
9,000	1.84E+00	0.0	2.33E+01	2.71E+00	0.0	0.00E+00
10,000	1.65E+00	0.0	4.95E+01	2.49E+00	0.0	0.00E+00

* End of operational period: 16 years







DATA SHEET 28 - calcium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	1		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation **16**
Years to Pit Flow-Through **50**

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	0	0
	1	73	34
Ore Stockpile East	0	0	0
	1	183	34
Ore Stockpile Southwest	0	N/A	1
	1	N/A	61
Tailings Facility	0	0	0
	1	73	34
ROM Ore Stockpiles	0	N/A	6
	1	N/A	79
Pit to Dipeta	0	51	52
	1	94	119
Pit to Mofia	0	N/A	59
	1	N/A	200

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	6.6371649	44.0519579	0.12060769
	b	2.82	4.13	Scenario 2	4.5340468	20.5575804	0.05628359
	c	-20	-20				
Full Contribu	a	0.03	0.06	Scenario 1	163.46	26,720	73
	b	-2.82	-4.13	Scenario 2	111.67	12,469	34
	c	-320	-320				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	9.66666996	93	0
	b	1.95	4.50	Scenario 2	4.17647876	17	0
	c	-20	-20				
Full Contribu	a	0.01	0.07	Scenario 1	258.18	66,659	183
	b	-1.95	-4.50	Scenario 2	111.55	12,443	34
	c	-350	-350				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	4.50	Scenario 2	14.3808742	207	1
	c	-75	-75				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-4.50	Scenario 2	149.312553	22,294	61
	c	-435	-435				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	6.637165	44	0
	b	2.82	4.13	Scenario 2	4.534047	21	0
	c	-20	-20				
Full Contribu	a	0.03	0.06	Scenario 1	163.463	26,720	73
	b	-2.82	-4.13	Scenario 2	111.6665	12,469	34
	c	-320	-320				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	5.81	Scenario 2	48.62808	2,365	6
	c	-400	-400				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-5.81	Scenario 2	170.2489	28,985	79
	c	-450	-450				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	23.25988	541	51
	b	8.36	6.69	Scenario 2	29.07484	845	52
	c	-250	-250				
Full Contribu	a	0.10	0.07	Scenario 1	127.25	16,192	94
	b	-8.36	-6.69	Scenario 2	159.06	25,301	119
	c	-600	-600				

Pit to Mofia, Post-closure

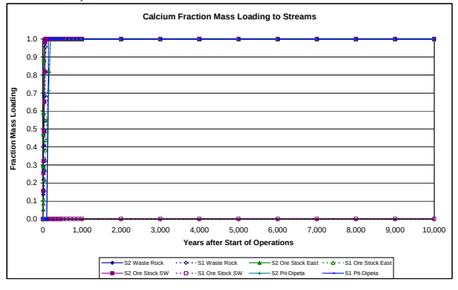
	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	6.41	Scenario 2	57.09683	3,260	59
	c	-500	-500				
Full Contribu	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-8.36	-6.41	Scenario 2	233.99	54,750	200
	c	-750	-750				

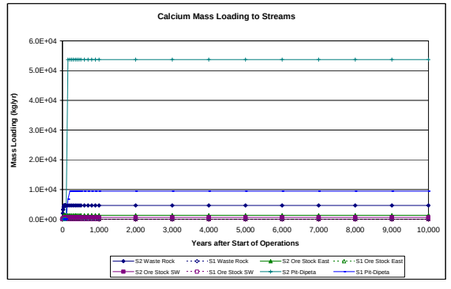
a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

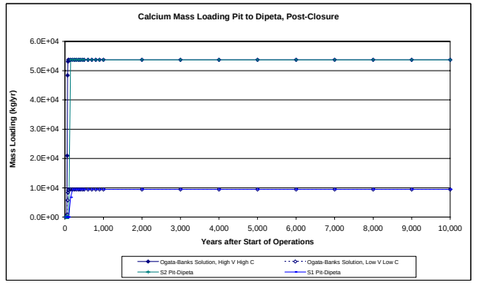
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading	Loading Calculations to Kasana (kg/year): Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S1, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	1.35E-01	5.35E-02	0.00E+00	1.35E-01	0.00E+00			2.92E-01	2.93E-01	1.56E-01	2.92E-01	4.84E-02			2.02E+03	7.87E+01	6.20E+02	7.71E+00	0.00E+00	0.00E+00	1.65E+02	0.00E+00	2.32E+00	0.00E+00				
16	2.17E-01	8.64E-02	0.00E+00	2.17E-01	0.00E+00			4.68E-01	4.69E-01	2.56E-01	4.68E-01	1.31E-01			3.23E+03	1.26E+01	9.94E+02	1.25E+01	0.00E+00	0.00E+00	2.70E+02	0.00E+00	6.26E+00	0.00E+00				
20	2.72E-01	1.08E-01	0.00E+00	2.72E-01	0.00E+00	0.00E+00	0.00E+00	5.85E-01	5.86E-01	3.21E-01	5.85E-01	1.86E-01	0.00E+00	0.00E+00	3.23E+03	1.26E+01	9.94E+02	1.25E+01	2.70E+02	0.00E+00	4.69E-01	1.84E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	4.09E-01	1.63E-01	0.00E+00	4.09E-01	0.00E+00	0.00E+00	0.00E+00	8.79E-01	8.80E-01	4.87E-01	8.79E-01	3.23E-01	0.00E+00	0.00E+00	4.07E+03	1.60E+01	1.14E+03	1.44E+01	3.16E+02	0.00E+00	7.05E-01	2.76E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	5.46E-01	2.18E-01	0.00E+00	5.46E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	6.52E-01	1.00E+00	4.60E-01	0.00E+00	0.00E+00	4.64E+03	2.13E+01	1.30E+03	1.92E+01	4.23E+02	0.00E+00	8.02E-01	3.69E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	6.83E-01	2.73E-01	0.00E+00	6.83E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	8.17E-01	1.00E+00	5.97E-01	0.00E+00	0.00E+00	4.64E+03	2.66E+01	1.30E+03	2.41E+01	5.30E+02	0.00E+00	8.02E-01	4.61E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	8.20E-01	3.28E-01	0.00E+00	8.20E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	9.83E-01	1.00E+00	7.34E-01	0.00E+00	0.00E+00	4.64E+03	3.20E+01	1.30E+03	2.89E+01	6.37E+02	0.00E+00	8.02E-01	5.54E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-01	0.8	2.10E+04	9.15E-01	0.2	9.25E+02
70	9.57E-01	3.83E-01	0.00E+00	9.57E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	8.72E-01	0.00E+00	0.00E+00	4.64E+03	3.73E+01	1.30E+03	3.38E+01	6.48E+02	0.00E+00	8.02E-01	6.46E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-9.12E-01	1.8	4.84E+04	-1.94E-01	1.2	5.75E+03
80	1.00E+00	4.38E-01	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	4.64E+03	3.90E+01	1.30E+03	3.86E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.60E+00	2.0	5.31E+04	-8.45E-01	1.8	8.36E+03
90	1.00E+00	4.92E-01	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	4.64E+03	3.90E+01	1.30E+03	4.35E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.13E+00	2.0	5.37E+04	-1.33E+00	1.9	9.17E+03
100	1.00E+00	5.47E-01	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	4.64E+03	3.90E+01	1.30E+03	4.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-2.57E+00	2.0	5.37E+04	-1.72E+00	2.0	9.39E+03
150	1.00E+00	8.22E-01	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	7.12E-01	2.91E-01	4.64E+03	3.90E+01	1.30E+03	7.25E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	6.74E+03	2.76E+03	2.76E+03
200	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	6.46E-01	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	6.11E+03	6.11E+03
250	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
300	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
350	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
400	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
450	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
500	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
600	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
700	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
800	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
900	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
1,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
2,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
3,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
4,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
5,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
6,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
7,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
8,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
9,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03
10,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.64E+03	3.90E+01	1.30E+03	8.83E+01	6.48E+02	0.00E+00	8.02E-01	6.75E-02	0.00E+00	0.00E+00	5.37E+04	9.46E+03	9.46E+03	9.46E+03

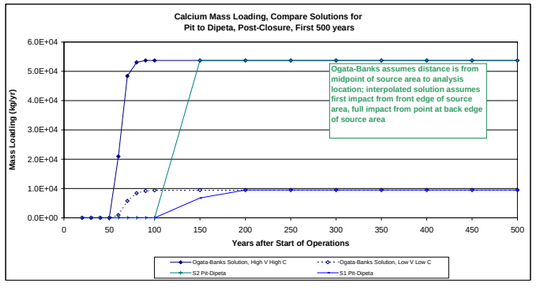
Ogata-Banks Solution, High V High C: Post-closure Loading to Dipeta, Scenario 1 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)	Ogata-Banks Solution, Low V Low C: Post-closure Loading to Dipeta, Scenario 2 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
1.97E-01	0.8	2.10E+04	9.15E-01	0.2	9.25E+02
-9.12E-01	1.8	4.84E+04	-1.94E-01	1.2	5.75E+03
-1.60E+00	2.0	5.31E+04	-8.45E-01	1.8	8.36E+03
-2.13E+00	2.0	5.37E+04	-1.33E+00	1.9	9.17E+03
-2.57E+00	2.0	5.37E+04	-1.72E+00	2.0	9.39E+03
-4.17E+00	2.0	5.37E+04	-3.09E+00	2.0	9.46E+03
-5.32E+00	2.0	5.37E+04	-4.06E+00	2.0	9.46E+03
-6.27E+00	2.0	5.37E+04	-4.85E+00	2.0	9.46E+03
-7.09E+00	2.0	5.37E+04	-5.52E+00	2.0	9.46E+03
-7.83E+00	2.0	5.37E+04	-6.13E+00	2.0	9.46E+03
-8.51E+00	2.0	5.37E+04	-6.68E+00	2.0	9.46E+03
-9.13E+00	2.0	5.37E+04	-7.19E+00	2.0	9.46E+03
-9.72E+00	2.0	5.37E+04	-7.66E+00	2.0	9.46E+03
-1.08E+01	2.0	5.37E+04	-8.53E+00	2.0	9.46E+03
-1.18E+01	2.0	5.37E+04	-9.32E+00	2.0	9.46E+03
-1.27E+01	2.0	5.37E+04	-1.01E+01	2.0	9.46E+03
-1.35E+01	2.0	5.37E+04	-1.07E+01	2.0	9.46E+03
-1.43E+01	2.0	5.37E+04	-1.14E+01	2.0	9.46E+03
-2.06E+01	2.0	5.37E+04	-1.65E+01	2.0	9.46E+03
-2.54E+01	2.0	5.37E+04	-2.03E+01	2.0	9.46E+03
-2.95E+01	2.0	5.37E+04	-2.35E+01	2.0	9.46E+03
-3.30E+01	2.0	5.37E+04	-2.64E+01	2.0	9.46E+03
-3.62E+01	2.0	5.37E+04	-2.89E+01	2.0	9.46E+03
-3.91E+01	2.0	5.37E+04	-3.13E+01	2.0	9.46E+03
-4.18E+01	2.0	5.37E+04	-3.34E+01	2.0	9.46E+03
-4.44E+01	2.0	5.37E+04	-3.55E+01	2.0	9.46E+03
-4.68E+01	2.0	5.37E+04	-3.74E+01	2.0	9.46E+03

* End of operational period: 16 years









DATA SHEET 29 - chloride

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	1		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	0	0
	1	73	34
Ore Stockpile East	0	0	0
	1	183	34
Ore Stockpile Southwest	0	N/A	1
	1	N/A	61
Tailings Facility	0	0	0
	1	73	34
ROM Ore Stockpiles	0	N/A	6
	1	N/A	79
Pit to Dipeta	0	51	52
	1	94	119
Pit to Mofia	0	N/A	59
	1	N/A	200

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	6.6371649	44.0519579	0.12060769
	b	2.82	4.13	Scenario 2	4.5340468	20.5575804	0.05628359
	c	-20	-20				
Full Contribu	a	0.03	0.06	Scenario 1	163.46	26,720	73
	b	-2.82	-4.13	Scenario 2	111.67	12,469	34
	c	-320	-320				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	9.66666996	93	0
	b	1.95	4.50	Scenario 2	4.17647876	17	0
	c	-20	-20				
Full Contribu	a	0.01	0.07	Scenario 1	258.18	66,659	183
	b	-1.95	-4.50	Scenario 2	111.55	12,443	34
	c	-350	-350				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	4.50	Scenario 2	14.3808742	207	1
	c	-75	-75				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-4.50	Scenario 2	149.312553	22,294	61
	c	-435	-435				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	6.637165	44	0
	b	2.82	4.13	Scenario 2	4.534047	21	0
	c	-20	-20				
Full Contribu	a	0.03	0.06	Scenario 1	163.463	26,720	73
	b	-2.82	-4.13	Scenario 2	111.6665	12,469	34
	c	-320	-320				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	5.81	Scenario 2	48.62808	2,365	6
	c	-400	-400				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-5.81	Scenario 2	170.2489	28,985	79
	c	-450	-450				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	23.25988	541	51
	b	8.36	6.69	Scenario 2	29.07484	845	52
	c	-250	-250				
Full Contribu	a	0.10	0.07	Scenario 1	127.25	16,192	94
	b	-8.36	-6.69	Scenario 2	159.06	25,301	119
	c	-600	-600				

Pit to Mofia, Post-closure

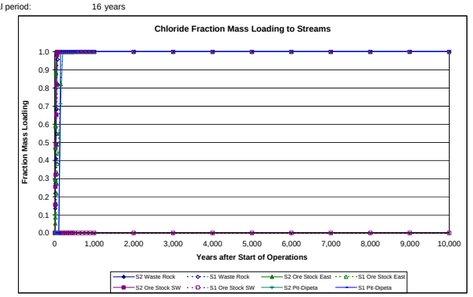
	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	6.41	Scenario 2	57.09683	3,260	59
	c	-500	-500				
Full Contrib	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-8.36	-6.41	Scenario 2	233.99	54,750	200
	c	-750	-750				

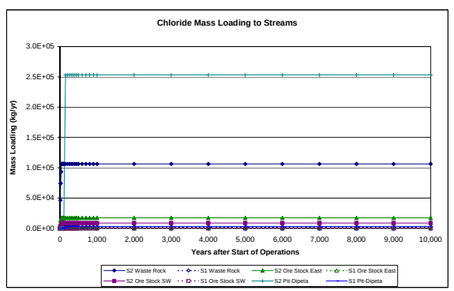
a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

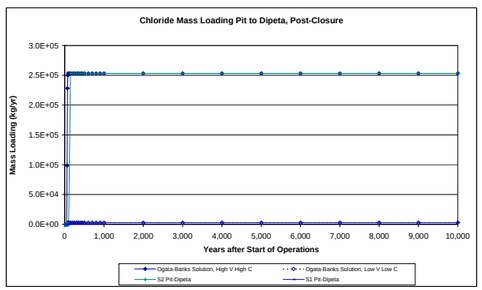
Time from Start of Operations (Years)*	Scenario 1: Kasana Waste Rock Fraction Mass Loading	Scenario 1: Ore Stock East Fraction Mass Loading	Scenario 1: Ore Stock SW Fraction Mass Loading	Scenario 1: Tailings Facility Fraction Mass Loading	Scenario 1: ROM Ore Stockpiles Fraction Mass Loading	Scenario 1: Pit to Dipeta Fraction Mass Loading	Scenario 1: Pit to Mofia Fraction Mass Loading	Scenario 2: Kasana Waste Rock Fraction Mass Loading	Scenario 2: Ore Stock East Fraction Mass Loading	Scenario 2: Ore Stock SW Fraction Mass Loading	Scenario 2: Tailings Facility Fraction Mass Loading	Scenario 2: ROM Ore Stockpiles Fraction Mass Loading	Scenario 2: Pit to Dipeta Fraction Mass Loading	Scenario 2: Pit to Mofia Fraction Mass Loading	Loading Calculations to Kasana (kg/year): Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00						
10	1.35E-01	5.35E-02	0.00E+00	1.35E-01	0.00E+00			2.92E-01	2.93E-01	1.56E-01	2.92E-01	4.84E-02			4.62E+04	3.40E+02	8.20E+03	1.05E+01	2.19E+03	0.00E+00	0.00E+00	0.00E+00	4.12E+00	0.00E+00						
16	2.17E-01	8.64E-02	0.00E+00	2.17E-01	0.00E+00			4.68E-01	4.69E-01	2.55E-01	4.68E-01	1.31E-01			7.41E+04	5.46E+02	1.31E+04	1.70E+01	3.58E+03	0.00E+00	0.00E+00	0.00E+00	1.11E+01	0.00E+00						
20	2.72E-01	1.08E-01	0.00E+00	2.72E-01	0.00E+00	0.00E+00	0.00E+00	5.85E-01	5.86E-01	3.21E-01	5.85E-01	1.86E-01	0.00E+00	0.00E+00	7.41E+04	5.46E+02	1.31E+04	1.70E+01	3.58E+03	0.00E+00	8.19E-02	3.35E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	4.09E-01	1.63E-01	0.00E+00	4.09E-01	0.00E+00	0.00E+00	0.00E+00	8.79E-01	8.80E-01	4.87E-01	8.79E-01	3.23E-01	0.00E+00	0.00E+00	9.33E+04	6.89E+02	1.51E+04	1.97E+01	4.17E+03	0.00E+00	1.23E-01	5.03E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	5.46E-01	2.18E-01	0.00E+00	5.46E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	6.52E-01	1.00E+00	4.60E-01	0.00E+00	0.00E+00	1.06E+05	9.20E+02	1.72E+04	2.63E+01	5.59E+03	0.00E+00	1.40E-01	6.71E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	6.83E-01	2.73E-01	0.00E+00	6.83E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	8.17E-01	1.00E+00	5.97E-01	0.00E+00	0.00E+00	1.06E+05	1.15E+03	1.72E+04	3.29E+01	7.01E+03	0.00E+00	1.40E-01	8.40E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	8.20E-01	3.28E-01	0.00E+00	8.20E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	9.83E-01	1.00E+00	7.34E-01	0.00E+00	0.00E+00	1.06E+05	1.38E+03	1.72E+04	3.95E+01	8.43E+03	0.00E+00	1.40E-01	1.01E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	9.57E-01	3.83E-01	0.00E+00	9.57E-01	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	8.72E-01	0.00E+00	0.00E+00	1.06E+05	1.61E+03	1.72E+04	4.61E+01	8.58E+03	0.00E+00	1.40E-01	1.18E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	1.00E+00	4.38E-01	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	1.06E+05	1.69E+03	1.72E+04	5.27E+01	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	1.00E+00	4.92E-01	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	1.06E+05	1.69E+03	1.72E+04	5.93E+01	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	1.00E+00	5.47E-01	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	1.06E+05	1.69E+03	1.72E+04	6.59E+01	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	1.00E+00	8.22E-01	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	7.12E-01	2.91E-01	1.06E+05	1.69E+03	1.72E+04	9.90E+01	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.07E+03	1.30E+04	8.47E+02		
200	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	6.46E-01	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	2.88E+04	1.88E+03		
250	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
300	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
350	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
400	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
450	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
500	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
600	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
700	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
800	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
900	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
1,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
2,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
3,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
4,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
5,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
6,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
7,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
8,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
9,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		
10,000	1.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.06E+05	1.69E+03	1.72E+04	1.20E+02	8.58E+03	0.00E+00	1.40E-01	1.23E-03	0.00E+00	0.00E+00	2.53E+05	2.91E+03	4.46E+04	2.91E+03		

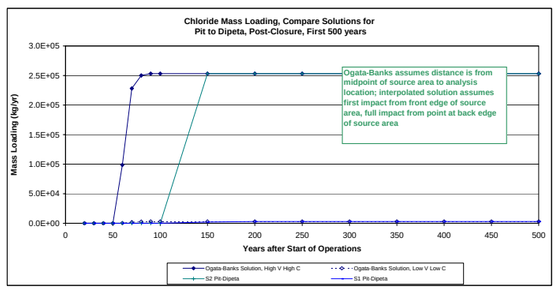
Ogata-Banks Solution, High V High C			Ogata-Banks Solution, Low V Low C		
Post-closure Loading to Dipeta, Scenario 1 (kg/yr)			Post-closure Loading to Dipeta, Scenario 2 (kg/yr)		
Beta	erfc (Beta)	Mass Loading (kg/yr)	Beta	erfc (Beta)	Mass Loading (kg/yr)
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
N/A	N/A	0	N/A	N/A	0
1.97E-01	0.8	9.88E+04	9.15E-01	0.2	2.84E+02
-9.12E-01	1.8	2.28E+05	-1.94E-01	1.2	1.77E+03
-1.60E+00	2.0	2.50E+05	-8.45E-01	1.8	2.57E+03
-2.13E+00	2.0	2.53E+05	-1.33E+00	1.9	2.82E+03
-2.57E+00	2.0	2.53E+05	-1.72E+00	2.0	2.88E+03
-4.17E+00	2.0	2.53E+05	-3.09E+00	2.0	2.91E+03
-5.32E+00	2.0	2.53E+05	-4.06E+00	2.0	2.91E+03
-6.27E+00	2.0	2.53E+05	-4.85E+00	2.0	2.91E+03
-7.09E+00	2.0	2.53E+05	-5.52E+00	2.0	2.91E+03
-7.83E+00	2.0	2.53E+05	-6.13E+00	2.0	2.91E+03
-8.51E+00	2.0	2.53E+05	-6.68E+00	2.0	2.91E+03
-9.13E+00	2.0	2.53E+05	-7.19E+00	2.0	2.91E+03
-9.72E+00	2.0	2.53E+05	-7.66E+00	2.0	2.91E+03
-1.08E+01	2.0	2.53E+05	-8.53E+00	2.0	2.91E+03
-1.18E+01	2.0	2.53E+05	-9.32E+00	2.0	2.91E+03
-1.27E+01	2.0	2.53E+05	-1.01E+01	2.0	2.91E+03
-1.35E+01	2.0	2.53E+05	-1.07E+01	2.0	2.91E+03
-1.43E+01	2.0	2.53E+05	-1.14E+01	2.0	2.91E+03
-2.06E+01	2.0	2.53E+05	-1.65E+01	2.0	2.91E+03
-2.54E+01	2.0	2.53E+05	-2.03E+01	2.0	2.91E+03
-2.95E+01	2.0	2.53E+05	-2.35E+01	2.0	2.91E+03
-3.30E+01	2.0	2.53E+05	-2.64E+01	2.0	2.91E+03
-3.62E+01	2.0	2.53E+05	-2.89E+01	2.0	2.91E+03
-3.91E+01	2.0	2.53E+05	-3.13E+01	2.0	2.91E+03
-4.18E+01	2.0	2.53E+05	-3.34E+01	2.0	2.91E+03
-4.44E+01	2.0	2.53E+05	-3.55E+01	2.0	2.91E+03
-4.68E+01	2.0	2.53E+05	-3.74E+01	2.0	2.91E+03

* End of operational period: 16 years









DATA SHEET 30 - magnesium

Parameters for Calcs	Retardation Factor	Scenario 1 GW Velocity (m/day)	Scenario 2 GW Velocity (m/day)
Retardation Factor	66781		
Kasana Waste Rock Dump		0.03	0.06
Ore Stockpile East		0.01	0.07
Ore Stockpile Southwest		N/A	0.05
Tailings Facility		0.03	0.06
ROM Ore Stockpiles		N/A	0.05
Pit to Dipeta		0.10	0.07
Pit to Mofia		N/A	0.04

 # Years of Operation 16
Years to Pit Flow-Through 50

Source	Dispersivity (m)	Short Dist (m)	Long Dist (m)	Avg Distance
Kasana Waste Rock Dump	17	20	320	170
Ore Stockpile East	19	20	350	185
Ore Stockpile Southwest	26	75	435	255
Tailings Facility	17	20	320	170
ROM Ore Stockpiles	43	400	450	425
Pit to Dipeta	43	250	600	425
Pit to Mofia	63	500	750	625

Summary of Bounding Time Frames, years after start of operations

Source	Fraction	Scenario 1 (yrs)	Scenario 2 (yrs)
Kasana Waste Rock Dump	0	8,054	3,759
	1	4,885,418	2,279,862
Ore Stockpile East	0	17,085	3,189
	1	12,187,753	2,275,047
Ore Stockpile Southwest	0	N/A	37,812
	1	N/A	4,076,199
Tailings Facility	0	8,054	3,759
	1	4,885,418	2,279,862
ROM Ore Stockpiles	0	N/A	432,352
	1	N/A	5,299,453
Pit to Dipeta	0	98,968	154,610
	1	2,960,609	4,625,924
Pit to Mofia	0	N/A	596,106
	1	N/A	10,010,344

Transport Parameters

Kasana Waste Rock

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	1715.17748	2941833.8	8054.30199
	b	728.58	1066.54	Scenario 2	1171.68928	1372855.77	3758.67426
	c	-1335620	-1335620				
Full Contribu	a	0.03	0.06	Scenario 1	42242.15	#########	4,885,418
	b	-728.58	-1066.54	Scenario 2	28856.88	#########	2,279,862
	c	-21369920	-21369920				

Ore Stockpile East

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.01	0.07	Scenario 1	2498.06279	6,240,318	17,085
	b	502.72	1163.58	Scenario 2	1079.28648	1,164,859	3,189
	c	-1335620	-1335620				
Full Contribu	a	0.01	0.07	Scenario 1	66720.14	#########	12,187,753
	b	-502.72	-1163.58	Scenario 2	28826.39	#########	2,275,047
	c	-23373350	-23373350				

Ore Stockpile Southwest

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	1163.19	Scenario 2	3716.30838	13,810,948	37,812
	c	-5008575	-5008575				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-1163.19	Scenario 2	38585.38	#########	4,076,199
	c	-29049735	-29049735				

Tailings Facility

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.03	0.06	Scenario 1	1715.177	#######	8,054
	b	728.58	1066.54	Scenario 2	1171.689	#######	3,759
	c	-1335620	-1335620				
Full Contribu	a	0.03	0.06	Scenario 1	42242.15	#######	4,885,418
	b	-728.58	-1066.54	Scenario 2	28856.88	#######	2,279,862
	c	-21369920	-21369920				

ROM Ore Stockpiles

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	1501.67	Scenario 2	12566.48	#######	432,352
	c	-26712400	-26712400				
Full Contribu	a	N/A	0.05	Scenario 1	N/A	N/A	N/A
	b	N/A	-1501.67	Scenario 2	43995.74	#######	5,299,453
	c	-30051450	-30051450				

Pit to Dipeta, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	0.10	0.07	Scenario 1	6010.822	#######	98,968
	b	2159.98	1727.99	Scenario 2	7513.527	#######	154,610
	c	-16695250	-16695250				
Full Contribu	a	0.10	0.07	Scenario 1	32883.80	#######	2,960,609
	b	-2159.98	-1727.99	Scenario 2	41104.75	#######	4,625,924
	c	-40068600	-40068600				

Pit to Mofia, Post-closure

	Quadratic factors	Scenario 1	Scenario 2	Solve for time	$t^{1/2}$	t = time to arrival (days)	t = time to arrival (years)
First arrival	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	N/A	1656.63	Scenario 2	14754.98	########	######
	c	-33390500	-33390500				
Full Contribu	a	N/A	0.04	Scenario 1	N/A	N/A	N/A
	b	-2159.98	-1656.63	Scenario 2	60467.01	########	######
	c	-50085750	-50085750				

a: velocity
b: 4*SQRT(dispersivity*velocity*retardation factor)
c: retardation factor * min. distance

Scenario 1

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9,000	1.94E-04	0.00E+00	0.00E+00	1.94E-04	0.00E+00	0.00E+00	0.00E+00
10,000	3.99E-04	0.00E+00	0.00E+00	3.99E-04	0.00E+00	0.00E+00	0.00E+00

Scenario 2

Time from Start of Operations (Years)*	Kasana Waste Rock Fraction Mass Loading	Ore Stock East Fraction Mass Loading	Ore Stock SW Fraction Mass Loading	Tailings Facility Fraction Mass Loading	ROM Ore Stockpiles Fraction Mass Loading	Pit to Dipeta Fraction Mass Loading	Pit to Mofia Fraction Mass Loading
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00		
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	1.06E-04	3.57E-04	0.00E+00	1.06E-04	0.00E+00	0.00E+00	0.00E+00
5,000	5.45E-04	7.97E-04	0.00E+00	5.45E-04	0.00E+00	0.00E+00	0.00E+00
6,000	9.85E-04	1.24E-03	0.00E+00	9.85E-04	0.00E+00	0.00E+00	0.00E+00
7,000	1.42E-03	1.68E-03	0.00E+00	1.42E-03	0.00E+00	0.00E+00	0.00E+00
8,000	1.86E-03	2.12E-03	0.00E+00	1.86E-03	0.00E+00	0.00E+00	0.00E+00
9,000	2.30E-03	2.56E-03	0.00E+00	2.30E-03	0.00E+00	0.00E+00	0.00E+00
10,000	2.74E-03	3.00E-03	0.00E+00	2.74E-03	0.00E+00	0.00E+00	0.00E+00

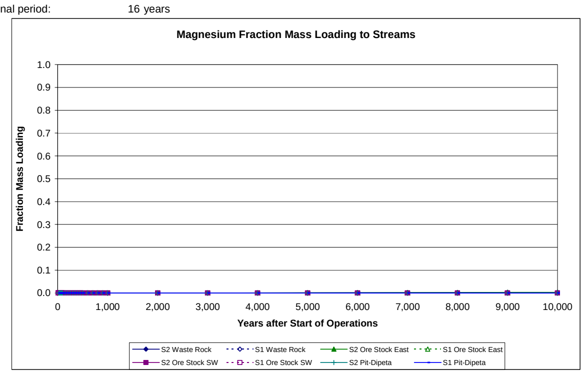
Loading Calculations to Kasana (kg/year)

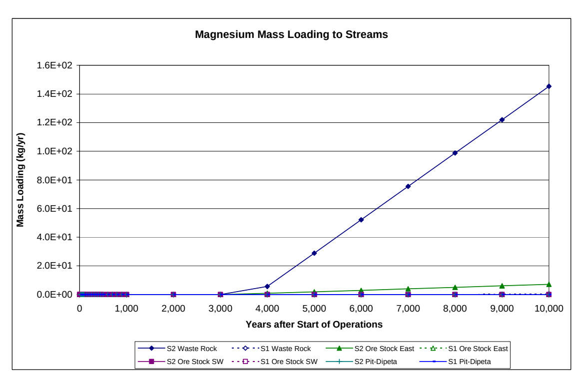
Time from Start of Operations (Years)*	Kasana Waste Rock Max (S2, High C)	Kasana Waste Rock Min (S1, Low C)	Ore Stockpile East Max (S2, High C)	Ore Stockpile East Min (S1, Low C)	Ore Stockpile SW Max (S2, High C)	Ore Stockpile SW Min (S1, Low C)	Tailings Max (S2, High C)	Tailings Min (S1, Low C)	ROM Ore Max (S2, High C)	ROM Ore Min (S1, Low C)	Pit-Dipeta Max (S1, High C)	Pit-Dipeta Min (S2, Low C)	Pit-Mofia Max (S2, High C)	Pit-Mofia Min (S2, Low C)
0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00				
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
150	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
200	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
250	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
300	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
350	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
400	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
450	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
500	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
600	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
700	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
800	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
900	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3,000	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4,000	5.62E+00	0.00E+00	8.49E-01	0.00E+00	0.00E+00	0.00E+00	2.50E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5,000	2.89E+01	0.00E+00	1.90E+00	0.00E+00	0.00E+00	0.00E+00	1.29E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6,000	5.22E+01	0.00E+00	2.94E+00	0.00E+00	0.00E+00	0.00E+00	2.32E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7,000	7.55E+01	0.00E+00	3.99E+00	0.00E+00	0.00E+00	0.00E+00	3.36E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8,000	9.88E+01	0.00E+00	5.03E+00	0.00E+00	0.00E+00	0.00E+00	4.40E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9,000	1.22E+02	2.01E-01	6.08E+00	0.00E+00	0.00E+00	0.00E+00	5.44E-04	1.57E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10,000	1.45E+02	4.14E-01	7.13E+00	0.00E+00	0.00E+00	0.00E+00	6.47E-04	3.23E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

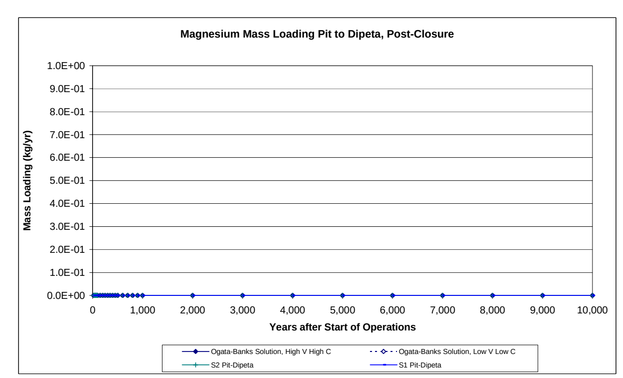
Ogata-Banks Solution

Time from Start of Operations (Years)*	Ogata-Banks Solution, High V High C — Post-closure Loading to Dipeta, Scenario 1 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)	Ogata-Banks Solution, Low V Low C — Post-closure Loading to Dipeta, Scenario 2 (kg/yr): Beta	erfc (Beta)	Mass Loading (kg/yr)
0						
10						
16						
20	N/A	N/A	0	N/A	N/A	0
30	N/A	N/A	0	N/A	N/A	0
40	N/A	N/A	0	N/A	N/A	0
50	N/A	N/A	0	N/A	N/A	0
60	4.35E+02	0.0	0.00E+00	5.44E+02	0.0	0.00E+00
70	3.08E+02	0.0	0.00E+00	3.84E+02	0.0	0.00E+00
80	2.51E+02	0.0	0.00E+00	3.14E+02	0.0	0.00E+00
90	2.17E+02	0.0	0.00E+00	2.72E+02	0.0	0.00E+00
100	1.95E+02	0.0	0.00E+00	2.43E+02	0.0	0.00E+00
150	1.38E+02	0.0	0.00E+00	1.72E+02	0.0	0.00E+00
200	1.12E+02	0.0	0.00E+00	1.40E+02	0.0	0.00E+00
250	9.72E+01	0.0	0.00E+00	1.22E+02	0.0	0.00E+00
300	8.70E+01	0.0	0.00E+00	1.09E+02	0.0	0.00E+00
350	7.94E+01	0.0	0.00E+00	9.92E+01	0.0	0.00E+00
400	7.35E+01	0.0	0.00E+00	9.19E+01	0.0	0.00E+00
450	6.87E+01	0.0	0.00E+00	8.59E+01	0.0	0.00E+00
500	6.48E+01	0.0	0.00E+00	8.10E+01	0.0	0.00E+00
600	5.86E+01	0.0	0.00E+00	7.33E+01	0.0	0.00E+00
700	5.39E+01	0.0	0.00E+00	6.74E+01	0.0	0.00E+00
800	5.02E+01	0.0	0.00E+00	6.27E+01	0.0	0.00E+00
900	4.71E+01	0.0	0.00E+00	5.89E+01	0.0	0.00E+00
1,000	4.46E+01	0.0	0.00E+00	5.57E+01	0.0	0.00E+00
2,000	3.11E+01	0.0	0.00E+00	3.89E+01	0.0	0.00E+00
3,000	2.52E+01	0.0	0.00E+00	3.16E+01	0.0	0.00E+00
4,000	2.18E+01	0.0	0.00E+00	2.73E+01	0.0	0.00E+00
5,000	1.94E+01	0.0	0.00E+00	2.43E+01	0.0	0.00E+00
6,000	1.77E+01	0.0	0.00E+00	2.22E+01	0.0	0.00E+00
7,000	1.63E+01	0.0	0.00E+00	2.05E+01	0.0	0.00E+00
8,000	1.53E+01	0.0	0.00E+00	1.92E+01	0.0	0.00E+00
9,000	1.44E+01	0.0	0.00E+00	1.80E+01	0.0	0.00E+00
10,000	1.36E+01	0.0	0.00E+00	1.71E+01	0.0	0.00E+00

* End of operational period: 16 years







APPENDIX C4.1-I

MACRO-ECONOMIC IMPACT ASSESSMENT

Tenke Fungurume Mining Project, Democratic Republic of the Congo: A Macro-Economic Assessment

Tenke Fungurume Mining S.A.R.L.
Democratic Republic of the Congo

Prepared by:

Chase Economics
Tacoma, Washington USA

March 2007

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1 INTRODUCTION

The objective of the macro-economics impact assessment of the proposed mine and mineral processing facility situated in the Tenke Fungurume area is to quantify the economic effects associated with the construction and operation of these facilities on the Democratic Republic of the Congo (DRC) economy. The economic effects emanating from the construction and operation of the proposed project are measured in terms of established macro-economic aggregates, including gross domestic product, exports, capital formation, employment and labor income, fiscal position, social services, and the current account of DRC's balance of payments.

Generally included in an overall impact assessment scope are the economic effects associated with the entire project complex, including any additional project-related requirements such as enhanced infrastructure (e.g., sewage treatment facility, access roads, water holding dam, transmission lines, labor housing) and land resettlement. This initial analysis includes these ancillary developments only in a cursory manner and as such is focused on the main project components of the mine and processing facilities.

2 PROPOSED PROJECT IN NATIONAL CONTEXT

The Democratic Republic of the Congo (DRC) is richly endowed with natural resources: fertile land; one of the largest tropical rain forests in the world; hydropower; and Africa's largest deposits of copper, cobalt and coltan (i.e., columbium [niobium] tantalum, locally referred to as "coltan"); along with significant reserves of other minerals, including gold, coal, diamonds, tin and zinc. Copper, cobalt, and diamonds are the key mineral commodities produced by the DRC.

The copper belt situated between DRC and Zambia is one of the world's greatest metallogenic provinces; it is estimated to contain 34 percent and 10 percent of global cobalt and copper reserves, respectively. The area contains the world's highest grades of copper and cobalt deposits, with tailings storage facilities often containing grades greater than that of most other mining areas. The proposed Tenke Fungurume Mining (TFM) project is located within this richly endowed metallogenic region.

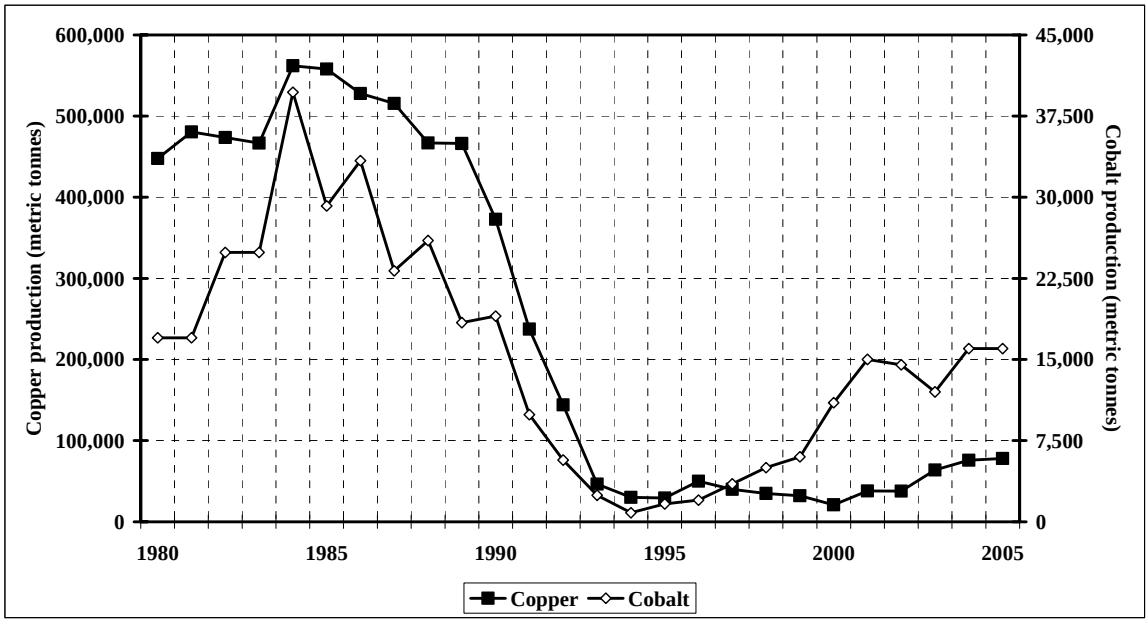
Natural resources figure prominently in the DRC economy. About 55 percent of its 2006 gross domestic product (GDP) of 8.5 billion USD[1] comes from agriculture, forestry and mining. Mining used to be the mainstay of DRC's economy. During the mid-1980s, the mining sector accounted for about one-fourth of the country's GDP, one-fourth of its fiscal revenue, and three-fourths of export receipts. At that time, DRC (called Zaire) was the world's largest producer and exporter of cobalt and the world's fifth largest producer of copper (Figure 1).

Between 1986 and 2001, DRC's formal mining[2] sector collapsed, due to large financial losses incurred by state enterprises operating in the sector, associated with mismanagement and a heavy tax burden that prevented them from maintaining the plant and equipment; and an economic environment hostile to private mining operations. The decline in formal mining was partially offset by a substantial increase in artisanal mining activities, particularly artisanal diamond mining.

1 USD refers to United States dollars.

2 Formal mining is based on a government-issued concession, stipulating an operator's rights and obligations concerning the exploration and exploitation of one or more geographically defined mining areas. Informal mining in contrast is not based on a government-issued concession and as such is in violation of existing legislation. Its activities are not systematically monitored and recorded.

Figure 1 Mining Production of Copper and Cobalt in Democratic Republic of the Congo: 1980 to 2005 (metric tonnes)



Source: United States Geological Survey (USGS), Mineral Commodity Summaries, Copper and Cobalt.
http://minerals.usgs.gov/minerals/pubs/mcs/

Reflecting its steep output slump, the mining sector's contribution to GDP and export earnings declined precipitously. While mining remained a major source of export receipts (due to diamond exports), it accounted for only a six percent share of GDP in 2000. The mining sector was plagued with serious problems that hampered its development. These problems included a legal and regulatory environment deleterious to private sector development, serious transportation issues and a chronic lack of private investment.

By 2001, when DRC initiated the process of macro-economic stability and re-opened its economy, the mining sector's "recorded" contribution to GDP had shrunk to about seven percent. Most sectors of the economy have steadily improved, with mining, manufacturing, construction and trade contributing significantly to national economic growth. In particular, recently implemented mining and investment codes are having a marked effect on private sector output. In 2006, the mining sector's share in the DRC's growing GDP had recovered to an estimated 14 percent (Table 1). However, these increases may be partly due to inflation.

Table 1 Annual Economic Indicators of Democratic Republic of the Congo

Annual Indicators	2001	2002	2003	2004	2005	2006
gross domestic product (nominal, US $billions)	6.8	5.5	5.6	6.6	7.1	8.5
gross domestic product (nominal, billions Congo francs)	1,407	1,922	2,284	2,610	3,368	4,157
real gross domestic product growth (percent)	-2.1%	3.5%	5.7%	6.8%	6.5%	6.4%
consumer price inflation (annual average, percent)	313.7%	38.1%	12.9%	4.0%	21.6%	16.0%
population (millions)	51.31	52.71	54.23	55.85	57.55	59.30
exports, free-on-board (nominal in US $millions)	880	1,076	1,340	1,813	2,050	2,350
imports, free-on-board (nominal in US $millions)	807	1,093	1,496	2,056	2,248	2,780
current-account balance (nominal in US $millions)	-252	-152	-83	-354	-345	-450
foreign direct investment, inflow (nominal, US $millions)	82	117	158	15	1,344	NA
copper production (thousand metric tonnes)	33.0	32.3	56.9	69.6	77.8	85.6
cobalt production (thousand metric tonnes)	15.0	11.9	7.3	8.9	8.2	7.9
Share of GDP						
agriculture & forestry	NA	NA	NA	42.5%	41.5%	41.4%
mining	NA	NA	NA	13.1%	13.4%	13.8%
industry	NA	NA	NA	11.9%	12.1%	12.0%
services	NA	NA	NA	30.4%	30.8%	31.1%

Sources: International Monetary Fund, Economic Commission for Africa, Economist Intelligence Unit (EIU) and Euromonitor International

3 STUDY OBJECTIVES AND APPROACH

The threefold objectives of this study are to:

- Identify potential economic impacts of the proposed TFM project.
- Estimate direct and indirect economic effects of the proposed TFM project within a cluster analysis perspective.
- Analyze the impact on selected economic sectors and economic aggregates such as GDP, government revenue and current balance.

Given the paucity of subnational socio-economic data and the unavailability of a national economic model (such as a social accounting matrix or input-output model) for the DRC, these economic impact results reported here represent best estimates. Information on the proposed mining project was provided by Phelps Dodge Corporation and economic data was obtained from various national and international sources.[3]

[3] Sources include Euromonitor International, Economist Intelligence Unit (EIU), International Monetary Fund, United Nations (UN) Economic Commission for Africa; World Bank; and Banque Centrale du Congo (Central Bank of the Democratic Republic of Congo).

4 ECONOMIC PROFILE OF PROPOSED TENKE FUNGURUME MINING PROJECT

The proposed TFM project will have an initial lifespan in excess of 20 years. About 2.1 million tonnes of copper and 262,000 tonnes of cobalt will be mined. Further processing of the ore will take place nearby. During its operation phase, the annual production will include 115,000 tonnes of Grade A copper cathode, 8,000 tonnes of high-grade electrowon cobalt, and 2,000 tonnes of cobalt as hydroxide intermediate. The mineral processing plant will mill and acid leach the ore followed by solvent extraction and electrowinning. Mining operations on the concession will likely be progressively scaled up, eventually reaching or exceeding 400,000 tonnes of copper annually.

The proposed site, located in the Katanga Province of the DRC midway between the copper mining towns of Likasi and Kolwezi, spans an area approximately 20 kilometers long. The concession area lies between the towns of Tenke and Fungurume mainly within a patchwork of small villages, agricultural and forested lands, along with mineralized lands that have undergone significant artisanal mining activities. The town of Tenke, with a population of around 11,000 people, is the regional transportation center, with a major railroad junction. Fungurume, a town of about 42,000 people, is the major trading center in the region.

Infrastructure development and ancillary facilities will include extensive access road improvements, a tailings storage facility, a limestone mine, a sulfuric acid plant, a health clinic, a potable water plant, sewage and waste treatment facilities, energy supply and transmission enhancement, and communications improvements. Construction personnel will be housed in a construction camp to be built at a site north of Fungurume. At the conclusion of the construction phase, residences will be converted to a permanent village.

Construction of the mine and related facilities and infrastructure is expected to take about 18 months starting during the first quarter of 2007, with formal operations beginning during the fourth quarter of 2008. Initial capital investment is estimated at 643 million USD for construction of the mine, associated processing facilities, and infrastructure improvements. The workforce is expected to peak at about 2,000 workers during the construction phase (Table 2).

Table 2 Tenke Fungurume Mining Project Characteristics

Project Characteristics	Total	DRC
capital investment, total	$643 million	$75 million
wages and salaries (construction)	$131 million	$65 million
plant and equipment	$474 million	$10 million
operating expenditures, annual	$163 million	$71 million
wages and salaries (operations)	$14 million	$8 million
supplies, materials, services	$130 million	$44 million
taxes paid	$18 million	$18 million
local development fund	$1 million	$1 million
Estimated Workforce Requirements		
construction, total (peak)	2,000 workers	1,210 workers
management	80 workers	10 workers
professional/technical	500 workers	100 workers
unskilled labor	1,420 workers	1,100 workers
operation, total (annual)	1,100 workers[(a)]	1,075 workers
management	26 workers	9 workers
professional/technical	499 workers	491 workers
unskilled labor	575 workers	575 workers

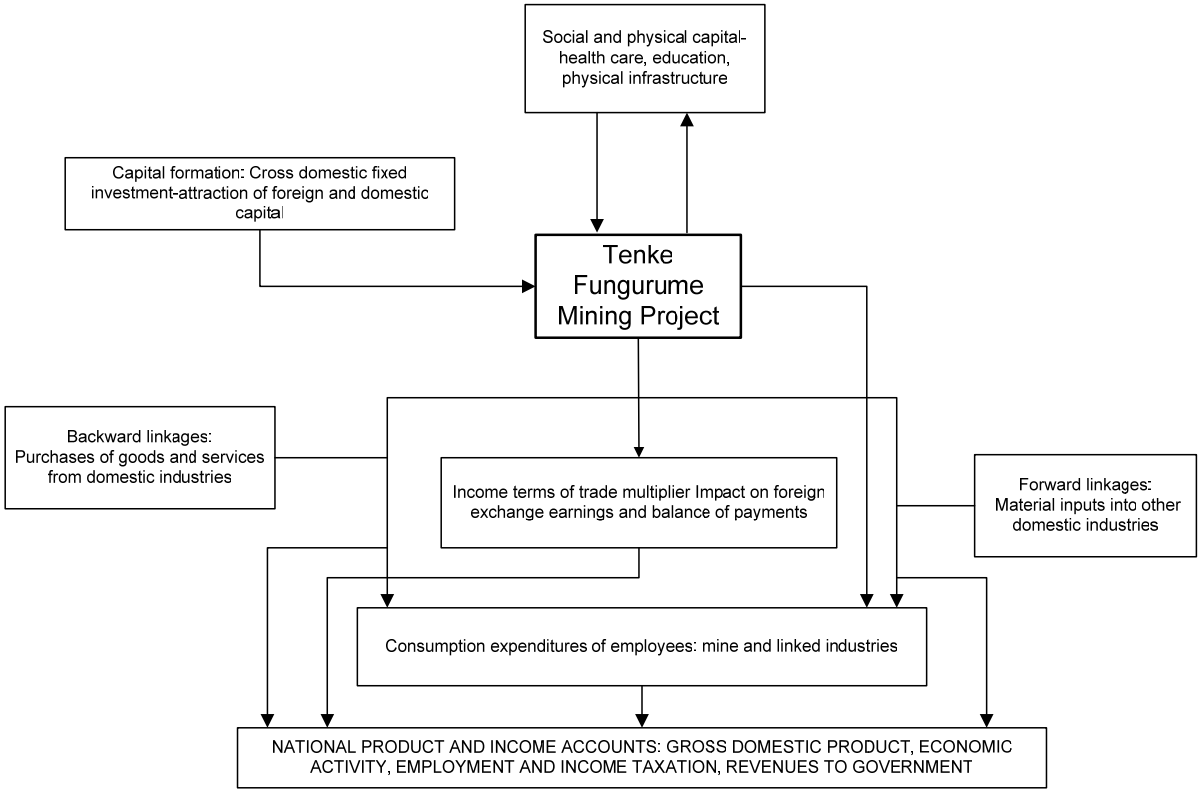
Note: Estimated in US dollars.
Source: Section A4; MinProc (2007)
[(a)] Includes 100 contractors.

Annual operating expenditures are estimated at 163 million USD over an initial 20-year operating phase. Of this total, 14 million USD is paid out for salaries and wages to the operations workforce; with the remainder for supplies, materials and services; taxes paid, and support for the local development fund.

5 CONTRIBUTION OF THE TENKE FUNGURUME MINING PROJECT TO THE DRC ECONOMY

This section analyzes the overall economic impact of the proposed TFM project on the DRC economy as a whole. The impact is measured in terms of its contribution to GDP, employment and income. The contribution of the project is not only a result of its direct activities, from initial investment to annual operations, but also various indirect activities, particularly local supply and support services, and induced activities (such as in trade and service sectors) supported by the spending behavior of workers directly or indirectly associated with the TFM project. A graphic synopsis of the overall economic contribution including different types of linkages of the TFM project is depicted in Figure 2.

Figure 2 Economic Impacts of Mining: TFM Project



5.1 DIRECT CONTRIBUTION

The direct contribution of the proposed TFM project to the national economy refers to the value added by the project itself, consisting of the wages and salaries of the approximate 1,100 project operation employees[4], gross profits of mining companies, net taxes paid (taxes minus subsidies). The estimated annual total direct contribution during operation is 27 million USD, equating to 0.3 percent of gross domestic product (8.5 billion USD).

The initial capital investment of the mining project constitutes a significant inflow of foreign capital; the approximate 643 million USD equates to nearly one-half of the Democratic Republic of the Congo's 2005 total in foreign direct investment.

Mining is the single most important earner of foreign exchange in the DRC economy. Based on current commodity prices, annual output from TFM project is expected to be valued at around 716 million USD. TFM's annual output will contribute to total exports from the DRC as well as its balance of payments.

5.2 INDIRECT IMPACT - LINKAGES

The TFM project will result in additional economic activity and employment opportunities other than the project itself during development, construction and operation, including employment from other sectors of the economy which provide inputs and services to the mining project and its employees. Thus, the final impacts from the project on output, income and employment will tend to be larger than the value of the mineral production and the number of the jobs in the project itself. The impact on other sectors can be divided into two major types: 1) the impact resulting from additional output in sectors that provide inputs to the mining operation; and 2) the impact resulting from increased household expenditures due to increases in income.

As is the case for many developing nations, the DRC lacks the industrial capacity that can provide copper and cobalt mining operations with the necessary complement of inputs in the form of supplies, materials and services. Most of the suppliers, particularly for capital goods and professional services, will be located outside of the country. Accordingly, the impact through suppliers (or backward linkages, see Figure 2) is attenuated. Still, major operating expenditures of the TFM project for supplies, materials and services provided by DRC vendors are estimated to amount to 44 million USD, annually.

[4] Approximately 1,000 employees and 100 contractors.

Based on operating cost estimates and supplemented with other mining studies completed elsewhere, the transport sector will be the largest supplier, accounting for nearly one-fifth of the total value of backward linkages to TFM (Table 3). This reflects on the significant reliance of the TFM project on the regional system for transporting inputs and supplies to the mining site for production and then transporting processed or semi-processed minerals to seaports for export. Much of TFM's transportation needs, particularly trucking and hauling to and from the mining site, will be contracted locally. Since all of the minerals from TFM will be exported, transport represents the only value that the export of TFM's processed minerals adds outside of the mining sector directly.

Table 3 Estimated Backward Linkages for the Proposed TFM Project

Materials, Supplies and Services Purchased	Annual Total Expenditures (millions USD)	Annual DRC Expenditures (millions USD)	Number of DRC Jobs
inland freight	$27.9	$8.2	347
reagents--process	$21.8	$3.9	183
maintenance materials	$18.9	$2.4	124
power	$18.1	$17.8	187
sulfur--sulfur acid plant	$12.2	$1.0	23
other operating materials & supplies	$10.5	$1.3	69
diesel/jet fuel	$9.9	$1.3	70
general & administration	$3.1	$3.0	118
explosives	$2.5	$0.1	6
outside services	$2.4	$2.3	162
contract operations	$1.2	$1.1	67
selling cost	$0.7	$0.7	39
professional services	$0.7	$0.6	25
contract maintenance	$0.1	$0.0	3
total materials, supplies and services purchased	$129.8	$43.7	1,423

Notes: Estimates provided by Chase Economics based on various sources.
Due to rounding conventions, numbers may not equal totals.

Sources: Supply and Use Tables of Mining, Statistics South Africa; United States (US) Input-output table, US Department of Commerce.

General and administration, outside services and contract operations combined for a significant share of the indirect employment; about 350 workers are estimated to be employed because of the TFM project.

The electricity sector will account for a significant percentage of TFM's operating expenditures, reflecting the high level of power consumption in

mineral processing of copper and cobalt. Electricity for the project will be purchased from the existing hydroelectric project in the DRC.

Combined, the estimated 44 million USD in expenditures of materials, supplies and services in operating the TFM project will employ an additional 1,423 workers.

There are also indirect impacts of the mining sector associated with downstream businesses; often referred to as forward linkages. Mineral production is either exported directly or sold to domestic producers (e.g., chemicals, primary metals) for use as inputs in their production of goods and services. The relevant wages and salaries and profits in these downstream industries sustained by mining business further contributes to GDP. In the case of the TFM project, the level of mineral exportation is presently indeterminate. Consequently, the extent of forward linkages to the TFM project and associated indirect impacts is uncertain.

5.3 INDUCED ECONOMIC CONTRIBUTION OF THE TFM PROJECT

The direct and indirect economic contribution of the TFM project sustains a multiplier process within the country, which results in an increase in incomes and employment exceeding the original contribution. Portions of wages and profits (net taxes and savings) are spent by businesses and workers within the local economy. Much of the spending occurs within local trade and services sectors, with some portion lost to imports and taxes paid; the rest, however, adds to the wages and profits of these local sectors. This economic rippling process repeats itself over several rounds, with successive additions to wages and profits being repeatedly divided between spending, savings and taxes.[5]

[5] Algebraically, this spending multiplier is estimated using the following formula:

k = 1/(1-(b-m)(1-t)).

where:

k = the spending multiplier factor.

b = the marginal propensity to consume locally, estimated to be 0.82 in 2006. This implies that the average consumer will spend 88 percent of any increase in their earnings (net of taxes) on goods and services; or they will save 12 percent of such an increase.

m = the marginal propensity to import, estimated to be 0.40 in 2006. This implies that on average 40 percent of any consumption expenditure made possible by the TFM project will be spent on imported goods and services.

t = the combined effective direct and indirect average tax rate and was estimated at 0.25 (i.e., 25 percent) in 2006.

Here, the spending multiplier for the TFM project was valued at 1.56 [= (1-(0.88-0.4)(1-0.25))]. Note that the value of this spending multiplier is dependent upon the imbedded assumptions of marginal propensity to consume locally; the marginal propensity to import and the effective average tax rate. Each of these values were estimated at conservative levels.

Within this report, the spending multiplier was calculated as 1.56; meaning that for every USD dollar in wages and salaries created by the TFM project, another 0.56 USD is added to the overall economy. In terms of job creation, an additional 2,400[6] workers are supported through the local spending for consumables by workers directly or indirectly connected to the TFM project.

5.4 MACRO-ECONOMIC SUMMARY OF THE TFM PROJECT

Minerals development has played an important role in the economy of the DRC. With the development of the proposed TFM project, mining will continue to be an engine of economic growth for the DRC.

The TFM project has a positive impact on the DRC's GDP. In addition, approximately 4,900 workers[7] will be employed in the DRC because of the TFM project; roughly four jobs will be added to the local economy for each direct TFM project job. Most of the jobs are expected to be created in the trade and service sectors; a significant number of jobs are created within the transportation and other raw materials sectors. This analysis does not take into account the informal job sector.

The operation of the TFM facility has a substantial positive impact on the DRC balance of payments to the extent of 617 million USD each year; that is, the value of exports exceeds the value of imports from economic activity associated with this facility.

In conclusion, the macro-economic impacts emanating from this proposed TFM project will result in significant benefits to the local area as in the country as a whole.

[6] Assuming an average annual wage of $5,000 and $12,000,000 of total wages of induced workers.

[7] Determined from 1,100 + 1,423 +2,400 = 4,923.

6 CONCLUSION

Mining and mineral wealth has traditionally been a significant economic sector within the DRC. The minerals industry has played a pivotal role in the economic development and establishment of infrastructure throughout the country.

The importance of mining to the DRC's economic development is projected to increase in the future. The World Bank and United Nations Economic Commission for Africa have identified the DRC as having vast potential for future development of its mineral resources. The proposed Tenke Fungurume Mining project confirms the substantial economic benefits derived from mineral development. Although TFM represents only one mining project, it underscores the potential that the mining and mineral resource sector could play in the economic future of the DRC.

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