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Environmental Impact Assessment Tenke Fungurume Project

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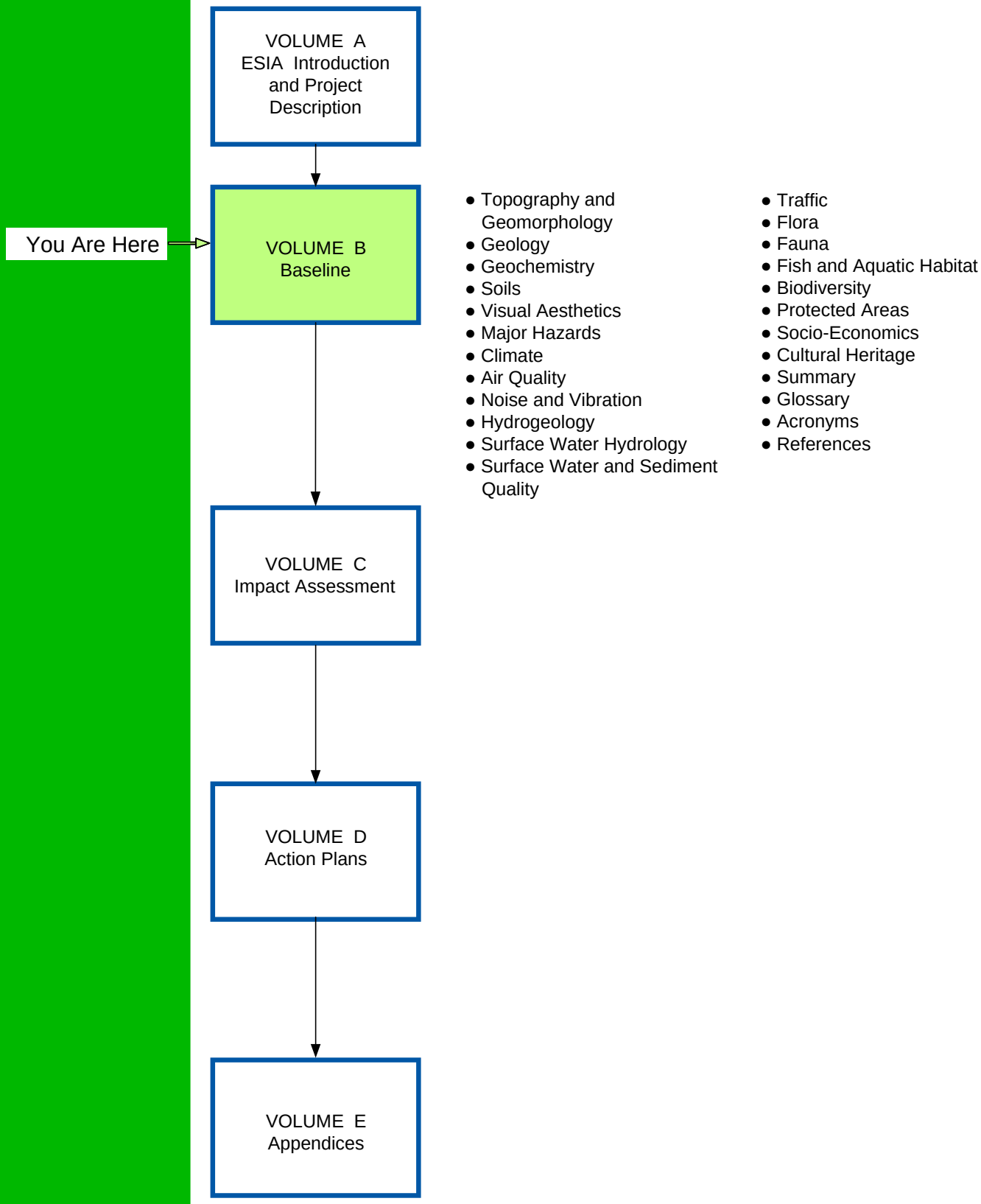
Golder Associates

Tenke Fungurume Project
Tenke Fungurume Mining SARL
Application Road Map



- Topography and Geomorphology
- Geology
- Geochemistry
- Soils
- Visual Aesthetics
- Major Hazards
- Climate
- Air Quality
- Noise and Vibration
- Hydrogeology
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APPENDIX B2.3-I

CONFIRMATORY MINE WASTE CHARACTERIZATION STUDY

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Attachment A Radioactivity Technical Memorandum

1 INTRODUCTION

Tenke Fungurume Mining (TFM) is investigating the feasibility of mining and processing copper and cobalt ore in a concession area in the Katanga Province of the Democratic Republic of the Congo (DRC). Mining activities associated with the proposed copper and cobalt mining project have the potential for short and long-term impacts on the local surface and groundwater resources. Specific project components that can impact on the composition and hence the quality of surface and groundwater include the waste rock facilities, ore stockpiles, open cast pits and the tailings storage facility (TSF).

Baseline geochemical work in the form of waste rock characterization (Knight Piésold 1998) and tailings characterization work (Knight Piésold 1997) was conducted in the 1990s. These studies were performed for a proposed development of the resource that never occurred. The 1990s project mine plan proposed development of the oxide ore body by open pit mining. Based on the Knight Piésold work, it was postulated that:

- The waste rock material derived from mining oxide ore only was not considered to have a significant potential for generating acid rock drainage (ARD) or metal leaching (ML). The potential existed, however, for 15 percent of the ore that would have been produced through the implementation of the 1990s project mine plan, to consist of transitional zone and sulfide zone ore. The transitional zone includes some oxide and some sulfide rock materials. The ARD and ML potential of these transitional and sulfide ores was not assessed in the above mentioned studies.
- The open pits were to be left to naturally fill with water after closure. Water qualities were expected to deteriorate during filling as historical weathering products were dissolved and reported to the pit lake. It was postulated, however, that the pit water quality would improve after re-filling to a composition representing background groundwater quality. These suppositions were not supported by a quantitative evaluation.
- The TSF was originally designed to receive a filtered (low moisture) tailing. Its design and location were different than that proposed for the current project. Seepage was expected to exit the TSF during operation and after closure (2 to 107 cubic meters per day according to Knight Piésold 1997). The tailings were to be deposited as a filter cake with lime treatment residue. The mineralogy and geochemistry of the combined tailings and treatment residue was not known. Leach tests conducted on earlier tailings indicated that the tailings could leach metals, although the tailings were expected to have a low ARD potential.

Based on the available information from the previous investigations, a number of geochemistry related knowledge gaps and risks were identified at the start of the current project and formed the basis for a confirmatory geochemical characterization program, the results of which are presented and evaluated in this document.

2 TERMS OF REFERENCE

Golder Associates (Golder) was contracted to conduct a confirmatory geochemical study aimed at building on the existing knowledge base and addressing specific geochemistry and water impact knowledge gaps. The geochemical study focuses on the Kwatebala oxide ore body and the objectives of the geochemical study can be summarized as follows:

Characterization of Mine Wastes

- Conduct confirmatory geochemical sampling, testing and analyses of materials used for the Waste Rock Characterization Study, Kwatebala Pit, Tenke Fungurume Project, prepared by Knight Piésold in 1998. Special emphasis was to be placed on the deeper, less weathered sections of the ore and waste rock (possible start of the transitional zone) not included in the previous waste rock characterization program.
- Conduct geochemical testing and analysis of ore materials that may be stockpiled on site temporarily during mining operations.
- Conduct geochemical testing and analysis of tailings solids that will be discharged to the TSF. The beneficiation process will result in a number of different residues, each with distinct geochemical characteristics. The geochemical nature of the material ultimately disposed in the TSF and potential impacts to water resources will depend on the timing and degree of co-mingling of these various residues.

Prediction of Mine Water Qualities

- Predict likely ranges of runoff and seepage qualities from the waste rock facilities and ore stockpiles during the operational and post-closure phases (waste rock facility only) of the planned mining project. This information will be used as an input into the environmental and social impact assessment (ESIA).
- Predict likely ranges in TSF supernatant and seepage water quality during the operational and post-closure phases of the project. This information will be used as an input to the ESIA and the tailings engineering feasibility study.
- Develop likely ranges of pit water qualities during the operational and post-closure phases of the planned Kwatebala pit. This information will be used as an input to the ESIA.

Mitigation

- Identify possible mitigation measures aimed at reducing the potential water resource impacts from the waste rock facility, ore stockpiles and TSF during the operational and post-closure phases of the planned TFM project.

3 PROJECT DESCRIPTION

3.1 GEOLOGY AND MINERALOGY

The geology of the Tenke Fungurume area is discussed in detail in the geology baseline (Section B2.2) and includes three ore body components (Kwatebala hills, Goma hills and Kavifwafwaulu [Fwaulu] hills). The following is a summary of the geology at the Kwatebala ore deposit.

The copper-cobalt ore body at Kwatebala exists within carbonaceous, sulfide-rich shale, siltstones, and arkoses of the Roan Group of the Proterozoic Katanga Super Group. The relevant formations and their lithologies of the Roan Group are described in Table 3.1-1.

Table 3.1-1 Geological Formations of the Tenke Fungurume Deposits

Upper Roan	Mwashia	Mw	silicified dolomite
	Mofia	Mo	limestone and dolomite
	Dipeta	Di	dolomitic schist, feldspathic sandstone and schist occasional mineralization
	RGS	RGS	sandy dolomite and feldspathic sandstone
Middle Roan	Calcaire B Minera Noire	CMN	siliceous dolomite and graphitic shale
	Schistes Dolomitiques	SD	dolomite and dolomitic shale, with copper (Cu) and cobalt (Co) mineralization at the base (upper ore body)
	Roches Siliceuses Cellulaires	RSC	coarse-grained siliceous dolomite, with some mineralization at the top and base
	Roches Siliceuses Feuilletees	RSF	laminated dolomitic shale with Cu and Co mineralization (lower ore body)
	Dolomite stratifié	D.Strat	stratified dolomite Cu and Co mineralization
Lower Roan	Roches Argil Talqueuses Gris	RATG	brecciated dolomitic and gray sandy shale
	Roches Argilo Talqueuses Lilac	RATL	brecciated dolomitic and lilac sandy shale

The ore body is confined to two beds of sulfidic, dolomitic shale varying in thickness from 5 to 15 meters, and separated by a silicified dolomitic unit. Thrusting and folding episodes have convoluted and segmented the Katanga sediments into discontinuous structural elements, including the Dipeta syncline

which hosts the ore body at Kwatebala. Figures 3.1-1 and 3.1-2 (at the back of this report) provide a plan view and cross sections of the Kwatebala ore body, geology and also indicate a potential pit layout.

The economic occurrence of the ore exists in three modes, namely:

- Oxide zone, where the mineralization is within the siliceous rocks. This zone consists of 100 percent oxide at surface and a gradual transition to sulfidic material deeper into the profile. The oxide zone varies from 50 to 150 meters depth below the surface.
- Sulfide mineralization, where the mineralization is within the dolomitic rocks in the form of sulfides.
- Mixed oxide and sulfides, i.e. transition zone from oxides to sulfides.

Chemical characterization of ore samples from the Kwatebala deposit shows that they represent high grade copper ores with an average grade of 2.1 percent copper and 0.3 percent cobalt (Section B2.2). The major copper and cobalt minerals in the oxide samples were found to be malachite [$Cu_2CO_3(OH)_2$], pseudomalachite [$Cu_5(PO_4)_2(OH)_4$], chrysocolla [$(Cu,Al)_2H_2Si_2O_5(OH)_4 \bullet nH_2O$], heterogenite [$CoO(OH)$], sphaerocobaltite [$CoCO_3$] and erythrite [$Co_3(AsO_4)_2 \bullet 8H_2O$] (Knight Piésold 1998).

The main ore minerals in the deeper sulfide zone include chalcocite [Cu_2S], digenite [Cu_9S_5], bornite [Cu_5FeS_4] and carrolite [$Cu(Co,Ni)_2S_4$] (Knight Piésold 1998).

Results from chemical analysis of ore samples are summarized in Table 3.1-2.

Table 3.1-2 Summary of Chemical Characterization of Ore (after the Geology Baseline – Section B2.2)

Metal	Range in Samples (P-2826)
copper (Cu)	3.8 to 6.25 %
cobalt (Co)	0.46 to 0.56 %
nickel (Ni)	trace amounts (30 to 37 ppm)
vanadium (V)	trace amounts (83 to 103 ppm)
mercury (Hg)	trace amounts (<1 ppm)
gold (Au)	detectable but not quantified
platinum (Pt)	detectable but not quantified
palladium (Pd)	detectable but not quantified
ruthenium (Ru)	detectable but not quantified
rhodium (Rh)	detectable but not quantified

Three waste rock lithologies were identified for the Kwatebala ore body (Knight Piésold 1998). These waste rock groups and their volumetric percentages in the open pit (according to the 1990s mine plan), include:

- RAT – Grises-Roches Argilo-Talqueuses: typical footwall formation occurring below the lower ore bed. This material was estimated by Knight Piésold to represent 18 percent of the pit waste rock volume.
- RSC – Roches-Siliceuses Cellulaires: unit separating the upper and lower ore beds. This material was estimated to represent 31 percent of the pit waste rock volume.
- SDS – Shales Dolomitiques Superieures: footwall formations above the upper ore bed. This material was estimated to represent 51 percent of the pit waste rock volume. This rock group is referred to as SD throughout this ESIA.

3.2 MINE FACILITIES

The confirmatory geochemistry study included investigations related to the following mining facilities:

- Kwatebala open cast pit.
- Kwatebala waste rock facility.
- Two long-term low-grade ore stockpiles.
- Short-term high-grade ore stockpiles.
- Tailings storage facility (TSF).

These mine facilities are described in detail in Section A4 (Project Description). The locations of these facilities are presented inA4.1-I of that report. A summary of the key aspects related to the environmental performance of these facilities is provided in the following sections.

3.2.1 Waste Rock Facility

- Waste rock will be hauled and end-tipped by truck from the planned Kwatebala pit.
- The maximum height of the Kwatebala waste rock facility will be approximately 100 meters.
- The waste rock facility will cover a footprint area of approximately 145 hectares. It should be noted that this footprint is based on the

mining of both the oxide and sulfide ore reserve, of which only the oxide ore is addressed in the ESIA. The footprint of the oxide-only waste rock facility will most likely be smaller.

- Runoff and toe seepage from the waste rock facility will normally be captured and directed to a storm water pond for use in the process water circuit. The storm water pond is designed to spill at a frequency of no more than once every ten years, on average. Storm water pond quality will be monitored. A more detailed description of storm water management is presented in Section A4 and the Feasibility Study (MinProc 2007).

3.2.2 Ore Stockpiles

- A short-term run-of-mine (ROM) ore stockpile, divided into up to six smaller stockpiles, each with varying copper and cobalt concentrations and varying degrees of permanence, are planned to allow blending of ore at the plant site. The short-term ROM ore stockpiles will be located adjacent to the plant site.
- Two long-term low-grade ore stockpiles will be located adjacent to the Kwatebala waste rock facility (referred to as the East and West stockpiles). These long-term ore stockpiles will be underlain by a compacted waste rock base. These stockpiles are scheduled to be processed beyond year 20.
- The planned dimensions (footprint area and height) of the ore stockpiles are shown in Table 3.2-1. Note that the footprint sizes assume the mining of both the oxide and sulfide ore reserve, and will most likely be smaller for the mining of oxide ore as addressed in the current ESIA.
- The ore stockpiles will be constructed by truck dumping and dozing. Front-end loaders will be used to selectively feed the primary crusher from the different ROM high-grade ore stockpiles.

Table 3.2-1 Ore Stockpile Dimensions

Ore Stockpile	Approximate Area (ha)	Approximate Volume (million tonnes)	Maximum Height (m)
short-term ROM stockpiles (up to 6)	6 (total for all 6)	0.64 [(a)]	10
East Stockpile	77	55 [(b)]	30
West Stockpile	38		30

(a) Approximate tonnage processed in a 3 month period.

(b) Project description (Table A4.3-2) indicates a tonnage of 54 million tonnes. Geochemical modeling to predict stockpile water qualities was based on earlier estimate of 55 million tonnes.

3.2.3 Open Pit

- The Kwatebala open pit will be mined over a period of approximately thirteen years (2008 to 2020). A plan view of the development of the pit is shown in Figure 3.1-1.
- The final footprint of the pit will be approximately 143 hectares.
- Production and development will be by conventional drill and blast methods. An ammonium nitrate /fuel oil (or used oil) mixture (ANFO) will be utilized as the principal blasting agent. Emulsion blasting agents may be used in areas of wetter and harder ground. The estimated average consumption of ANFO will be about 2,350 tonnes per year and 2,050 tonnes per year for blasting of waste rock and ore, respectively (Baloo 2006).
- An option exists to use a surface miner to obtain the ore. This would reduce the amount of drilling and blasting required.
- Blasted waste rock and ore will be hauled from the pit by trucks via an access ramp to the north of the pit.
- Pit water during the operation phase will consist of storm water. Dewatering wells will be designed to intercept groundwater inflow. The pit storm water will be pumped from the pit into the storm water management system that manages water affected by mining activities.
- The post-closure in-pit water management objective is to achieve steady state in-pit water levels dictated by natural conditions (Section D5 – Reclamation and Closure Plan).

3.2.4 Tailings Storage Facility (TSF)

- The TSF receives milled, leached and neutralized mineral residue from the plant and is comprised of two general facilities: main tailing pond (TSF) and the return water dam (RWD).
- The main tailing impoundment has a storage capacity of 115 million tonnes.
- The tailing impoundment will be lined and the embankment constructed predominantly from compacted waste material sourced from the mine pre-stripping operations.
- The tailings will be discharged from the plant thickeners as slurry containing approximately 54 percent water by weight. The design tailings solids discharge rate is 314 tonnes per hour (this rate includes the neutralized tailings, the FAM base metal residue and reagents) (Section A4 – Table A4.10-1).

- The tailings are described as a fine grained sandy silt with traces of clay and are classified as SM (i.e., sand with silty fines) under the Unified Soil Classification System (USCS).

Excess process water will be removed and disposed during the decommissioning phase. The surface of the TSF will be reclaimed to be stable over the long term and to ensure that it is not a source of dust and/or contaminated surface runoff (Section D5).

3.3 MINE PLAN

Mining of the Kwatebala pit is scheduled to commence in the fourth quarter of 2008. Several months prior, some pre-stripping of the overburden will occur. Mining of the ore will rapidly ramp up to a production rate of about 7,000 tonnes per day ore and approximately 16,000 to 17,000 tonnes per day of low grade ore. In subsequent years, low-grade ore will be mined at variable rates (Section A4).

The proposed schedule for development of the Kwatebala, Goma and Fwaulu ore bodies is shown in Table 3.3-1 (as presented in Table A4.1-1 of the Project Description).

Table 3.3-1 Proposed Schedule of Ore Body Development

Ore Body	Mining Area	When Mined
Kwatebala	Kwatebala pit	2008 to 2016, 2020, and 2023 to 2026
Goma	Goma pit	2017 to 2020, and 2025
Fwaulu	Fwaulu pit	2020 to 2022, and 2027

As discussed in the terms of reference, the geochemical study focuses on the Kwatebala oxide ore body. The current mine plan indicates that this ore body will be mined from 2008 to 2016 and then again in 2020 and 2023 to 2026.

4 GEOCHEMICAL CHARACTERIZATION PROGRAM

4.1 OVERVIEW OF CHARACTERIZATION PROGRAM

The goal of the geochemical characterization program is to characterize the ARD and ML potential of mine wastes. Typically, a mine waste characterization program will begin with static testing followed by kinetic testing if deemed appropriate. The objective of static testing is to describe the bulk chemical characteristics of a waste material. These tests are designed to evaluate the potential of a waste material to leach metals or generate acid. If static testing indicates an ARD/ML potential, kinetic testing may be conducted to verify whether the various ARD/ML potentials identified will indeed be realized over time.

The 1998 Knight Piésold waste rock characterization study included static testing (i.e., acid base accounting (ABA) and synthetic precipitation leach procedure (SPLP)) of 21 composite samples of exploration core from the Kwatebala deposit. The 2006 geochemical waste rock testing program was designed to augment and confirm the available waste rock geochemical characterization data, and also included geochemical characterization of tailings and ore. Tailings geochemical characterization data collected during the 1990s characterization program were not included in the current evaluation. Due to differences in the proposed beneficiation process, the tailings data collected previously are not considered representative of the tailings that will be generated as part of the current project.

A site visit was conducted to collect relevant materials from the mining site, targeting ore exposures that have been exposed by previous mining, as well as any exploration core samples that were available in storage on-site. Various on-site samples were taken at Kwatebala, including artisanal mine waste from historic mining activities (referred to as artisanal material throughout this report). Geological models and cross sections were consulted in order to identify suitable core samples. Selected old and recently drilled cores were sampled for confirmation of the Knight Piésold waste characterization work. Additional core samples were also collected from the deeper parts of the ore body, potentially representing transitional ore material. Core samples were selected, cut and crushed on-site.

The above samples were submitted for a range of static and kinetic geochemical tests. The test results were then interpreted and used for prediction of likely discharge qualities from the various mine facilities.

4.2 SAMPLE SELECTION

4.2.1 Waste Rock

Core was sampled for two purposes: firstly, confirmatory sampling related to the Knight Piésold waste characterization work; and secondly, to sample deeper waste rock for characterization of materials with sulfide mineral assemblages. The sampling strategies for these purposes were distinctly different and are discussed in more detail below.

4.2.1.1 Sampling of Cores for Confirmatory Work

The 1998 Knight Piésold work focused on the three types of waste rock identified for the Kwatebala ore deposit (see Section 3.1), including: (1) the footwall formation of the lower ore zone (Grises-Roches Argilo-Talqueuses or "RAT"); (2) the unit separating the upper and lower ore beds (Roches-Siliceuses Cellulaires or "RSC"); and, (3) the footwall formations above the above the upper ore bed (Shales Dolomitiques Superieures and similarly overlying units, collectively identified as "SDS" or "SD" in the current ESIA). These materials were expected to represent all oxide waste material in the proposed Kwatebala pit. According to the 1998 Knight Piésold report, 51 percent (by volume) of the pit waste rock was expected to consist of the SDS (referenced as SD in the current ESIA) type waste rock, 31 percent of the RSC and 18 percent of the RAT.

The Knight Piésold work included sampling of multiple short intervals within each selected waste rock intercept in cores chosen on specific cross sections and representing a particular waste rock type over that portion of the longitudinal length of the pit. A total of 368 individual 10-centimeter core intervals were collected and combined into 21 composite samples (seven of each waste rock type). These composite samples were then submitted for standard static geochemical tests.

In the current round of sampling, cores from both 1997 core ("TKA series") and older core ("K" series) were sampled as per the previous work (Photograph 4.2-1). Two composite samples of each waste rock type were randomly selected from the Knight Piésold sample list for confirmatory characterization. The same cores used for preparation of the composite samples (as described in Appendix A of the Knight Piésold report) were sampled again to generate the same composite sample. These samples are described in Table 4.2-1.

Photograph 4.2-1 Drill Core for Sample Selection ("K" Series)

4.2.1.2 Sampling of Cores for Deeper Ore Zone Characterization

A detailed pit layout was not available at the time of sampling. A number of cross sections were therefore studied to select boreholes/cores that intersect the main ore zone, also referred to as the RSF – Roches Siliceuses Feuilletees (see Table 3.1-1) at greatest depth and potentially within the pit layout.

Digital copies of the cross sections and logs were not available and hard copies were studied on-site with the resident geologist instead. Figure 4.2-1 shows a photograph of the cross section lines, cross sections and logs evaluated on-site.

Logs for the selected boreholes were then perused to evaluate the weathered nature of the material at depth and any references to sulfide mineral assemblages. Sampling intervals were selected for those cores referencing un-weathered material and/or sulfide mineral assemblages. Sub-samples were taken across an interval, as defined in Table 4.2-2, to provide material for a composite sample of each lithology from each borehole in which it was represented. Samples were collected in intervals of one to four meters to obtain sufficient representative material of a particular lithological unit for analysis.

The selected cores and the intervals sampled are provided in Table 4.2-2.

Table 4.2-1 Core Samples Taken for Confirmatory Work

Golder Sample ID	Waste Rock Type	Composite Sample	Cores and Intervals (m)[a]
SD-OX	SD	SD 20100	TKA 038 – 5, 10, 15, 20
			TKA 0056 – 11, 17, 22, 27, 32, 37, 42
			TKA 018 – 125, 130
		SD 21100	TKA 001A – 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120, 125
			K31.0/9.55 – 5, 10, 15, 20, 25
			K31.0/8.9 – 5, 10, 15, 20, 25
RSC-OX	RSC	RSC 19800 -19600	TKA 35 – 38, 46, 53
			K18.0/4.97 – 60, 65, 70, 75, 80
			TKA 028 – 46, 51, 57
			TKA 034 – 17, 22, 27, 74, 79, 83, 88,
			TKA 026 – 63, 68, 73
		RSC 20500 – 20300	TKA 022 – 4, 10
			TKA 023 – 7, 13, 20
			TKA 030 – 48, 68, 93, 114, 119
			TKA 009 – 4, 10
			TKA 003 – 2
			TKA 031 – 55, 30, 65
			K23.0/6.8 – 65, 70, 75, 80
			K23.0/7.4 – 115, 120, 125, 130
RAT-OX	RAT	RAT 19900 -19600	TKA 035 – 80
			TKA 036 – 23, 28
			TKA 034 – 48
			TKA 028 – 77
			TKA 016 – 23
			TKA 014 – 30
			TKA 002 – 69
		RAT 20200	TKA 008 – 36
			TKA 011A – 28
			TKA 025 – 72, 77
			TKA 027 – 40
			TKA 003A – 20, 25, 30, 35, 40, 45, 50, 55

[a] 10 cm core samples taken at each interval.

Table 4.2-2 Samples Selected to Characterize Deeper Waste Rock

Borehole /Core	Golder Sample ID	Interval	Description of Sample[(a)]
TKA 002	SD-S	95.63 m 101.56 m	SDB dolomitic shale. Pale white pink – eutherite – weathered
	SD-S	101.56 m 124.83 m	SD dolomitic shale, Massive, fine grained, orange brown, malachite sporadic
TKA 039	RSC-S	255.65 m 274.85 m	RSC – scattered crystals of chalcopyrite oxidized in some places to malachite
	RSC-S	274.85 m 285.00 m	Thinly banded dolomitic shales Malachite and heterogenite at contact with RSC – fresh + oxidized
TKA 040	RSC-S	166.40 m 185.00 m	RSC – Massive, pinkish siliceous
	RSF-S	185.00 m 194.40 m	RSF – Finely banded siliceous dolomitic shale. Moderate amounts of chalcopyrite, bornite and chalcocite
TKA 41	RSC-S	255.15 m 275.45 m	RSC – Siliceous rock
	RSF-S	275.45 m 288.33 m	RSF – Dolomitic shale with chalcocite, bornite and chalcopyrite
K 29.0/9.1	RSF-S	169.90 m 191.70 m	RSF – Laminated banded siliceous shale
	RSC-S	191.70 m 200.00 m	RSC – chert dolomite (no mention of sulfides)
TKA 037	RSC-S	79.60 m 89.60 m	RSC – Sample last 10 m
	RSF-S	89.60 m 103.30 m	RSF – Malachite, chalcocite, siliceous dolomite
K19.0/5.75	RSF-S	88.70 m 109.70 m	RSF – Pink gray siliceous dolomite, chalcocite
	RSC-S	110.80 m 113.80 m	RSC - Massive siliceous rock

(a) Copied directly from core logs.

4.2.1.3 Waste Rock Sample Representativeness

The original sampling plan developed by Knight Piésold for the 1998 waste rock characterization study was designed to account for lithological variability within the oxide zone of the proposed Kwatebala pit. The sampling plan involved the characterization of waste rock types at different points along the east –west axis of the pit that parallels the structural axis of the deposit. Composite samples were identified by the cross section or group of cross sections from which they were derived.

Samples were selected by Knight Piésold by examining cross sections on either end of the pit and identifying the available drill cores on the cross section which intercepted a given waste rock type. In some cases, intercepts from several successive cross sections were combined to represent the waste rock type over a finite longitudinal length of the Kwatebala pit.

The Knight Piésold sampling program attempted to collect a number of samples that were representative for each waste rock type consistent with the total estimated volume of waste rock to be generated from the Kwatebala pit. However, no formal statistical analyses were conducted to evaluate sample representativeness. Since no additional core material was available, the current sampling program adopted the methodology developed by Knight Piésold for both the confirmatory work and the sampling of deeper waste rocks, as discussed in the previous sections.

The Knight Piésold characterization program did not include any samples representative of the deeper, less weathered sections of the ore and waste rock (possible start of the transitional zone). The designation of ore grade is not based on sulfide content but rather metallurgy (i.e., ore is defined as material in which greater than 85 weight percent of the contained copper is acid soluble during ore processing), which is only tangentially related to weathering of sulfide minerals. The current study included characterization of a limited number of samples selected as representative of waste from the transitional zone. Due to the limited number of deeper core samples, the representativeness of the samples from deeper waste rock material (i.e. transitional or sulfide material) can not be quantified. Superposition of the "TKA" series deep samples (see Table 4.2-2) on the current pit layout indicates that these samples are located outside the current pit extents. The "TKA" portions of the sulfide samples are therefore not representative of waste rock that will be generated during mining of the oxide ore body. Information on the position of the "K" series samples relative to the anticipated pit extents was not available.

The sampling effort conducted for the current study was part of a confirmatory assessment intended to provide support to the mine planning process.

4.2.2 Artisanal Mine Material and Site Ponded Water

Two samples of artisanal mine waste from Fungurume Hill were collected for inclusion in the waste rock characterization study (Photographs 4.2-2 to 4.2-4). The primary objective of this effort was to characterize the particle size distribution of existing waste rock. However, the ARD/ML potential of these samples was also determined. These artisanal material samples are referred to as "Artisanal 1" and "Artisanal 2" throughout this report. As will be discussed in Section 5.2.1, due to the elevated copper and cobalt contents of these materials, these samples are considered more representative of high-grade ore than waste.

Photograph 4.2-2 Fungurume Hill

Photograph 4.2-3 Collection of Artisanal Material Samples

Photograph 4.2-4 Copper Mineralization in the Vicinity of Artisanal Material Sample

The Kwatebala ore body was visited on January 23, 2006 after extensive rain in the area. Various pools of runoff water were visible on the various waste rock piles from previous artisanal mining activities. One such pool was sampled to get an indication of possible waste rock runoff water qualities.

No visible toe seepage was noted at any of the existing waste rock facilities. However, a number of the old diggings (rat holes), especially lower down the slope, contained standing water. Two such pits were sampled as being potentially representative of waste rock seepage qualities. It is, however, expected that the qualities would represent seepage from weathered material and not that of freshly exposed waste rock.

Two water samples were collected from each site, one filtered on site using a peristaltic pump. Filtered samples were acidified with concentrated nitric acid before storage in cooler boxes and subsequent cooling in refrigerators. Samples were submitted to the laboratory for chemical analysis.

4.2.3 Tailings and Ore Samples

The proposed metallurgical process for the extraction of cobalt and copper is presented in the project description (Section A4). In summary, the beneficiation process includes crushing, grinding, leaching, solvent extraction, purification and electrowinning of cathode copper and cobalt. Run-of-mine (ROM) ore will be crushed and leached with sulfuric acid and sulfur dioxide to dissolve the copper and cobalt. Slurry from the leach circuit will be thickened. Leach circuit overflow will report to the high-grade pregnant leach solution pond and the thickened slurry will be transferred to the counter current decantation (CCD) circuit. The CCD circuit will wash copper and cobalt from the solids. Washed solids (i.e., tailings) from the CCD circuit will be the primary waste material.

In addition to tailings, the beneficiation process will produce two other waste materials: (1) iron/aluminum/manganese (FAM) precipitated residue from the cobalt recovery circuit; and (2) magnesium hydroxide [$Mg(OH)_2$] precipitated residue from the cobalt recovery circuit.

Throughout the project development phase, a number of waste disposal options have been considered. The three waste disposal options evaluated, in chronological order, are summarized below.

- ***Segregation of the three waste streams***. During the initial stages of project development, segregation of the three waste materials (i.e., tailings, FAM and $Mg(OH)_2$) was proposed. The tailings were to be discharged as a slurry to the TSF following neutralization to pH 9 with lime. The FAM and $Mg(OH)_2$ wastes (collectively referred to as the base metal (BM) residues) were to be discharged to separate lined facilities.

- ***Co-mingling of the tailings and $Mg(OH)_2$*:** The second disposal option involved co-mingling of the tailings and $Mg(OH)_2$ prior to discharge to the TSF. The $Mg(OH)_2$ waste stream was to be added to the tailings during the neutralization process to raise the pH of the tailings slurry to approximately 8. Lime was then to be added to further raise the pH of the combined waste stream to approximately 10.2 (instead of 9) prior to discharge. The FAM solids were to be discharged to a lined repository located within the footprint of the TSF, but the FAM material was to remain physically isolated from the tailings. The only interaction between the TSF and the FAM repository was to be discharge of runoff from the FAM repository into the TSF. The pH of the FAM pore water was expected to be much lower than that of the tailings (i.e., 3.5). As described in

Section A4 (Project Description), the FAM residue is a waste product produced in the cobalt recovery circuit. Barren solution (raffinate) from solution extraction will be neutralized to a pH of 3.5 using limestone. A mixture of sulfur dioxide and air will be sparged into mechanically agitated reactors to assist in the precipitation of FAM.

- ***Co-mingling of the tailings, $Mg(OH)_2$ and FAM***: The current waste management plan involves combining all three wastes prior to disposal to the TSF. Following mixing, the combined waste material will be neutralized to a pH of approximately 10.2 by the addition of lime. The estimated composition of the waste stream is predicted to be as follows: 91.4 weight percent CCD underflow (tailings), 6.5 weight percent FAM, 1.4 weight percent lime and 0.7 weight percent $Mg(OH)_2$.

Because the geochemical characterization program was conducted concurrent with development of the waste management plan, an understanding of its history is required to appreciate the development of the tailings and ore geochemical characterization program. Metallurgical testing for the project was conducted by Hazen Research Inc. (Hazen). Testing of the so-called “bench upper”, “bulk upper” and “bulk upper/lower” ore samples has been completed. Descriptions of these ore and tailings samples (supernatant and solids) provided to Golder for geochemical characterization are presented below. A summary of these samples is presented in Table 4.2-3 for reference. The metallurgical testing samples provided in the latter stages of the program are considered most representative of the waste materials that will be generated during mining. As such, characterization data from these samples are used in the prediction of TSF water quality in Section 6.5. For completeness, the origins and geochemical results of all samples are presented in this report.

Table 4.2-3 Summary of Tailings and Ore Samples Provided by Hazen

Date (Test Type)	Ore Source (Name and Description)	Samples Provided for Geochemical Characterization					Spike[a]	Notes
		Ore	Tailings Solids (Slurry)	Tailings Water (Supernatant)	FAM Residue	$Mg(OH)_2$ Residue		
Feb-06 (flume test)	**Bench Upper** – Sample was collected from surface trenches and is therefore representative of ore in the early stages of development.	-	-	-	-	-	Mn	Hazen conducted neutralization testing of flume test tailings generated from batch processing of the upper ore. Hazen provided Golder solution chemistry results at pH 8.2, 9.0 and 10.
Mar-06 (flume test)			tailings neutralized to pH 7	samples following neutralization to pH 7	-	-	Mn	Samples were collected following rinsing of tailings with tap water.
Jun-06 (flume test)	**Bulk Upper** – A composite of 7 of the 25 bulk ore samples collected in Nov/Dec 2005. The 7 samples were from the upper ore zone.	bulk sample crushed to minus ½ inch	tailings neutralized to pH 9	samples collected during neutralization at target pH values of approx. 3, 7.5, 8 and 9	-	-	none	
Aug-06 (flume test)	**Bulk Upper/Lower** – A composite of selected samples from the 25 bulk ore samples collected in Nov/Dec 2005. Sample mixture is as follows: 72% lower, 22% upper and 4% intermediate, 2% undefined.	-	-	combined tailings/$Mg(OH)_2$ samples collected during neutralization at pH values of approx. 9 and 10	-	-	none	
Aug-06 (2nd pilot test)		-	combined tailings/$Mg(OH)_2$ neutralized to pH 10	combined tailings/$Mg(OH)_2$ collected during neutralization at pH values of approx. 3, 9 and 10	cake sample	Supernatant sample collected prior to combining with tailings	none	

[a] In the early stages of metallurgical testing it was anticipated that manganese would be leached from the ore. Manganese was therefore added to simulate leaching. In the latter stages of testing, it was decided that addition of manganese was not representative of expected conditions.

4.2.3.1 Bench Upper Ore

The bench upper ore sample was collected from ground surface in the area of the Kwatebala pit. This sample is therefore considered representative of ore that will be processed in the very early stages of mining.

In February 2006, Hazen conducted neutralization testing of tailings generated from processing of the bench upper ore. This test was intended to characterize the lime requirement for neutralization of simulated washed flume tailings slurry. The pH of the tailings slurry was raised in a stepwise fashion from 2.9 to approximately 10 by the addition of lime. Solution chemistry was analyzed at pH 8.2, 9.0 and 10. Hazen provided Golder with the solution chemistry results.

In March 2006, flume testing of the bench upper tailings was conducted. Tailings for flume testing were generated as follows:

1. The bench upper ore sample was crushed and leached.
2. Bench upper tailings generated from Step 1 were rinsed with approximately three volumes of Golden City tap water.
3. Bench upper tailings were mixed with limestone to raise the slurry pH to neutral (pH ~7).
4. Neutralized tailings from Step 3 were slurried with tap water in the flume.

Supernatant and slurry samples from Step 4 (i.e., following dilution in the flume) were provided to Golder for geochemical characterization. The supernatant sample was labeled as flume overflow (O/F). The tailings slurry was labeled as flume underflow (U/F). The flume overflow sample is considered representative of tailings supernatant. The underflow sample is referenced as the “bench upper tailings” samples throughout this report.

The following issues are noted with respect to the representativeness of the bench upper tailings and supernatant samples provided for geochemical characterization:

1. The bench upper ore sample was collected from surface trenches and is therefore considered representative of ore that will be mined in the very early stages of development. Likewise, the bench upper tailings are considered representative of tailings that will be generated in the very early stages of mining.

2. Because the "Flume U/F" and "Flume O/F" were collected following slurry with tap water, measured concentrations in the supernatant (Flume O/F) may

be underestimated (i.e., diluted). The composition of the tailings solids may also have been compromised by additional washing.

3. The bench upper tailings were neutralized to pH 7 which is not representative of the degree of neutralization that will occur during operation (i.e., tailings slurry will be neutralized to approximately pH 10 prior to discharge).

4. During simulation of the leach process, manganese (Mn) was added to the leach solution. The manganese concentration in the Flume O/F sample is therefore elevated.

4.2.3.2 Bulk Upper Ore

From November 21 to December 8, 2005, bulk ore sampling of the Kwatebala deposit was conducted by Phelps Dodge. Twenty-five (25) one-tonne samples were collected for metallurgical testing. The sampling program targeted samples from the upper portions of the ore body, to be mined in the first eight years, that would be representative of "typical" ore (i.e., four to five percent copper grade) (Schuh 2005).

Nineteen of the twenty-five bulk ore samples were collected from 30-year old exploration trenches. Sample collection avoided C-horizon (i.e., broken rocks from the base of the soil level), A-zone and B-zone soils. Nevertheless, all rocks from the trenches are expected to be softer and potentially more clayey than what will be mined at deeper levels in the ore zone (Schuh 2005).

The remaining six samples were collected from underground adits (30 to 50 meters below ground surface) advanced by SMTF between 1973 and 1975. The adit samples are considered more representative of what will be mined in the future as they are less susceptible to the effects of surface weathering (Schuh 2005).

During the bulk ore sampling campaign, a high quality limestone sample from the Mofia quarry was also collected.

Seven of the bulk ore samples collected from the upper ore zone were composited to form the bulk upper ore sample. Hazen provided Golder a sample of the bulk upper ore, crushed to minus one half inch.

In June 2006, Hazen conducted flume testing of tailings generated from processing of the bulk upper ore sample. Prior to flume testing, the bulk upper tailings slurry was neutralized to pH 9 with Mofia limestone. Golder requested that supernatant samples be collected prior to neutralization (at the starting pH value of approximately 3), at two intermediate pH values (approximately 7 and

8) and at the final pH value (9). Hazen measured pH and conductivity on site. Because the slurry samples did not settle sufficiently to produce a supernatant sample for analysis, slurry samples were filtered through sharkskin paper and the solution recovered. A portion of this solution was further filtered (0.45 µm). Filtered (0.45 µm) and unfiltered (passed through the sharkskin paper only) were provided to Golder for chemical analysis.

Hazen also provided a sample of neutralized tailings slurry (pH 9) for geochemical characterization. The tailings slurry sample was collected by Golder personnel from the flume discharge area. This sample is referenced as the bulk upper tailings sample throughout this report.

4.2.3.3 Bulk Upper/Lower Ore

In August 2006, Hazen conducted testing of the bulk upper/lower ore. The bulk upper/lower ore sample was a composite of selected samples from the bulk ore sampling campaign. The sample distribution by ore type was as follows: 72 percent lower ore, 22 percent upper ore, 4 percent intermediate ore and 2 percent undefined. Based on the current mine plan, this ore sample is considered most representative of the ore that will be generated during operations.

In August 2006, co-mingling of the tailings and $Mg(OH)_2$ wastes prior to neutralization and discharge was being considered. Hazen conducted flume testing of a combined tailing/$Mg(OH)_2$ sample. Hazen provided Golder supernatant samples collected during neutralization with lime/limestone at pH values of approximately 9 and 10.

Hazen also provided Golder with samples collected from the 2nd pilot test. The 2nd pilot test was conducted in August 2006. Tailings produced during this test were combined with $Mg(OH)_2$ and neutralized to pH 10 with lime and limestone. Hazen furnished a tailings slurry sample and tailings supernatant samples collected at target pH values of 3, 9 and 10. A sample of the $Mg(OH)_2$ supernatant, collected prior to mixing of this waste with the tailings, was also provided, as was a sample of the FAM residue (described as a cake sample).

The tailings/$Mg(OH)_2$ samples provided to Golder from the flume and pilot testing of the bulk upper/lower ore are referred to as the combined tailings sample throughout this report. The bulk upper/lower ore samples generated for the flume and pilot test were not from the same batch; however, they both contained the same ore distribution.

4.2.4 Open Pit

Geological materials that will be exposed during open pit mining activities include ore and waste rock. Representative samples of these materials were collected as described in Sections 4.2.1 and 4.2.3, respectively. The results of the waste rock geochemical characterization program were used for prediction of pit lake water quality.

4.3 ANALYTICAL METHODS

The geochemical characterization program is summarized in Table 4.3-1. This table includes both the program conducted previously by Knight Piésold (1998) as well as the Golder supplemental effort conducted as part of the current study. The table shows the number of samples collected and analyzed, and the components of the geochemical characterization programs. Descriptions of each of the components of the geochemical characterization program are provided in the following sections.

The principal laboratories for the Knight Piésold and Golder studies are listed below. Portions of the analytical work that were subcontracted to other laboratories are identified throughout this report.

- Knight Piésold (1998) waste rock characterization – Lakefield Research Limited (Lakefield), Lakefield, Ontario, Canada.
- Golder waste rock characterization (current study) – Waterlab (Pty) Ltd. (Waterlab), Pretoria, South Africa.
- Golder tailings and ore characterization (current study) – Canadian Environmental Metallurgical Inc. (CEMI), Burnaby, British Columbia, Canada.

Table 4.3-1 Summary of Geochemical Characterization Programs

		Knight Piésold (1988)		Current Study (2006)							
		ARD	ML	ARD		ML		Composition		Physical Properties	
		ABA	SPLP	ABA	NAG	SPLP	Column Leach	Elemental Analysis	Mineralogy XRD	Particle Size	Moisture Content
waste rock	SD-OX [(a)]	7	7	1	1	1	1	1	1	1	-
	RSC-OX	7	7	1	1	1	1	1	1	1	-
	RAT-OX	7	7	1	1	1	1	1	1	1	-
	SD-S	-	-	1	1	1	-	1	1	-	-
	RSC-S	-	-	1	1	1	-	1	1	-	-
	RSF-S	-	-	1	1	1	-	1	1	-	-
	artisanal material	-	-	2	2	2	-	2	2	-	-
ore	bulk upper	-	-	1	1	1	1	1	1	1	-
tailings	bench upper	-	-	1	1	1	1	1	1	1	1
	bulk upper	-	-	1	-	1	-	1	1	1	1
	combined	-	-	1	1	1	1	1	1	1	-
	FAM	-	-	1	1	1	-	1	-	1	-
total number of samples analyzed		21	21	13	12	13	6	13	12	8	2

[(a)] Referenced as SDS in the Knight Piésold report.

ARD – Acid Rock Drainage.

ML – Metal Leaching.

ABA – Acid Base Accounting.

SPLP – Synthetic Precipitation Leaching Procedure.

NAG – Net Acid Generation.

XRD – X-ray Diffraction.

4.3.1 Physical Properties

4.3.1.1 Particle Size Distribution

Waterlab subcontracted particle size analysis of six waste rock and two artisanal waste samples to Soillab (Pty) Ltd., of Pretoria, South Africa. Sieve analysis and hydrometer analysis were conducted to characterize the greater than two millimeters and less than two millimeter fractions, respectively. The waste rock samples were crushed to minus 13.2 millimeters prior to sieve analysis. Particle size analysis was conducted on the artisanal material samples as received.

CEMI conducted particle size analysis of the ore and tailings samples. Particle size analysis was conducted on the samples as received. The analyses were conducted using a Ro-Tap sieve shaker. A pre-weighed sample was placed on the top screen and put on the Ro-tap for 15 minutes. Each size fraction (down to

the less than two millimeter size fraction) was weighed. Results were presented as a percentage of the total weight.

4.3.1.2 Moisture Content

CEMI determined the moisture content of the bench upper tailings and bulk upper tailings samples. Excess water was drained from each tailings slurry sample. A 500-gram sample was air dried. The wet weight and dry weight of the tailings samples were measured to calculate their moisture contents.

4.3.2 Chemical/Mineralogical Composition

4.3.2.1 Mineralogical Analysis

Mineralogical analysis of waste rock samples was not included in the geochemical characterization study conducted by Knight Piésold (1998). As part of the current study, samples of waste rock, tailings and ore were submitted to laboratories in South Africa and Canada for mineralogical analysis by X-ray diffraction (XRD).

The six waste rock and two artisanal material samples included in the current study were analyzed by the Council for Geoscience in Pretoria, South Africa using quantitative XRD. Phase identification was based on the SIEMENS DIFFRACPlus - EVA evaluation program using the JCDD (JCPDS) Inorganic/Organic Database. Phase concentrations were determined as semi-quantitative estimates, using relative peak heights/areas proportions (Brime 1985).

The bench upper tailings, bulk upper ore and combined tailings samples were submitted by CEMI to the Department of Earth and Ocean Sciences at the University of British Columbia, Canada, for quantitative XRD analysis using the Rietveld method. The X-ray diffractograms were analyzed using the International Center for Diffraction Database PDF-4 using Search-Match software by Siemens (Bruker). X-ray powder-diffraction data were refined with Rietveld Topas 3 (Bruker AXS). Results were presented as the relative amount of crystalline phase normalized to 100 percent.

The bulk upper tailings sample was submitted by CEMI to PetraScience Consultants Inc. of Vancouver, British Columbia, Canada for qualitative XRD analysis. At the time of sample submission, the laboratory at the University of British Columbia could not meet the requested deadline for mineralogical analysis. The X-ray diffractograms were analyzed using the International Center

for Diffraction Database PDF-4 using Search-Match software by Siemens (Bruker). Rietveld refinement was not performed. Qualitative XRD analysis was used to identify the major, minor and trace mineral components of the sample.

4.3.2.2 Whole Rock Chemistry

Chemical analysis of waste rock samples was not included in the characterization study performed by Knight Piésold (1998). As part of the current study, waste rock, tailings and ore samples were analyzed by laboratories in South Africa and Canada for elemental and whole rock composition.

The six waste rock and two artisanal material samples were submitted to the Council for Geoscience in Pretoria, South Africa for whole rock elemental analysis by X-ray fluorescence (XRF) spectrometry.

Tailings and ore samples were submitted by CEMI to Acme Analytical Laboratories of Vancouver, British Columbia for elemental analysis. Elemental concentrations were determined by inductively coupled plasma mass spectrometry (ICP-MS) following a one hour Aqua Regia digestion at 95 degrees Celsius.

The bulk upper tailings sample was submitted by CEMI to Assayers Canada Ltd. of Vancouver, British Columbia for whole rock analysis by XRF.

4.3.3 Acid Rock Drainage Potential

4.3.3.1 Acid Base Accounting (ABA)

Acid-base accounting (ABA) is conducted to predict the acid neutralizing potential (NP) and acid generation potential (AP) of a material. ABA analysis included determination of the following:

- Bulk neutralization potential (NP).
- Carbonate neutralization potential (CaNP) by total inorganic carbon (TIC) analysis.
- Paste pH.
- Acid potential (AP) by sulfur determination (total sulfur - S(T); sulfide sulfur - $S(S^{-2})$; and sulfate sulfur - $S(SO_4)$).

The Knight Piésold (1998) study included ABA analysis of 21 waste rock samples by Lakefield. Detailed descriptions of their analytical procedures are provided in Appendix B of Knight Piésold's report (1998). Bulk NP was determined according to the modified Sobek (low temperature) procedure.

ABA analysis of the six waste rock and two artisanal material samples included in the current study was conducted by Waterlab. Bulk NP was determined using the modified Sobek method. ABA analysis did not include determination of TIC.

CEMI conducted ABA analysis of tailings and ore samples following the standard Sobek procedure. Total sulfur and sulfate-sulfur analysis was subcontracted to Assayers Canada Ltd. ABA analysis did not include determination of TIC on the bulk upper ore and the bench upper tailings samples.

4.3.3.2 Net Acid Generation (NAG) Test

A second type of acid-base accounting, developed initially in Australia but now widely applied internationally, is called the Net Acid Generation (NAG) procedure. The NAG procedure uses a strong oxidant (hydrogen peroxide) to rapidly oxidize sulfide minerals in a crushed sample of the entire rock (AMIRA 2002). The NP of the sample then can be directly challenged by the acidity generated by rapidly oxidizing sulfides. If the sample has sufficient available NP, the alkalinity of the whole rock will not be entirely depleted, and the system is expected to have the capacity to remain circum-neutral. If there is inadequate available NP, then the pH of the test solution will fall below 4.5 and there will be net acidity rather than net alkalinity. In this case, a sample shows potential for acid generation.

NAG analysis was conducted on a 2.5 gram sample in 250 milliliters of lixiviant, resulting in a solid to solution ratio of 100 : 1. To evaluate metal leaching, NAG leachates were analyzed for a comprehensive suite of metals.

NAG testing of the six waste rock and two artisanal material samples was conducted by Waterlab. NAG test leachates were analyzed for pH, sulfate, chloride and 70 elements by inductively coupled plasma mass spectrometry (ICP-MS).

NAG testing of the bench upper tailings and bulk upper ore sample was conducted by CEMI. Leachates were analyzed for pH and 38 elements by ICP-MS.

NAG testing of the combined tailings and FAM residue samples was conducted by CEMI. NAG pH was recorded. NAG test leachates were not analyzed for a comprehensive suite of parameters.

4.3.4 Metal Leaching Potential

4.3.4.1 Short-Term Leach Testing

The Environmental Protection Agency's Synthetic Precipitation Leaching Procedure (SPLP) (EPA Method 1312) was designed to assess the environmental stability of a waste material following contact with rain water. The test, designed for sites in the United States, stipulates a lixiviant with a pH of 4.2 or 5.0 for sites located east or west of the Mississippi River, respectively. The former lixiviant is considered representative of "acid rain" generated in industrialized areas, whereas the latter lixiviant is considered representative of more rural environments. The target pH is attained by addition of a 60 percent sulfuric/40 percent nitric acid solution.

The standard SPLP protocol is as follows:

- Sample particle size: minus-9.5 millimeters.
- Solution to solid ratio: 20 to 1 by weight.
- Reaction time: 18 hours.

The short-term nature of the SPLP test provides a snapshot in time of a material's environmental stability. Test results depend entirely on the present disposition of the sample (e.g., unoxidized vs. oxidized; oxidation products absent vs. present, etc.). For reactive rocks, the mechanisms that lead to changes in solution chemistry during water-rock interactions often develop over periods of time that are much greater than can be represented in an 18-hour extraction test (e.g., sulfide oxidation).

The Knight Piésold (1998) study included SPLP testing of 21 waste rock samples by Lakefield. SPLP testing followed the standard protocol outlined above using a pH 4.2 lixiviant. SPLP leachates were analyzed for pH, conductivity, total dissolved solids (TDS), anions (F, Cl, SO_4 and alkalinity), cations (Ca, Mg, Na and K), nutrients (phosphate, nitrate and nitrite) and 19 elements.

SPLP testing of the six waste rock and two artisanal material samples collected for the confirmatory characterization program was conducted by Waterlab. The SPLP testing followed the standard protocol outlined above; however, samples

were crushed to minus 13.2 millimeters. To be consistent with the Knight Piésold study, a pH 4.2 lixiviant was used. Use of a pH 4.2 lixiviant is considered conservative with respect to the assessment of potential environmental impacts. The pH of site rainwater is expected to be higher than 4.2, which is deemed representative of "acid rain" in an industrialized area. SPLP leachates were analyzed for pH, conductivity, anions (F and Cl), ortho-phosphate and 70 elements by ICP-MS.

SPLP testing of the bench upper tailings, bulk upper tailings, combined tailings, FAM residue and bulk upper ore sample was conducted by CEMI. SPLP testing was performed on samples as received (i.e., sample particle size was not reduced). The bench upper tailings and bulk upper ore samples were tested with two lixiviants: nanopure water with no pH adjustment (pH 6.2) and standard pH 4.2 lixiviant. Leachates were analyzed for pH, conductivity and 37 elements by ICP-MS. The bulk upper tailings, combined tailings and FAM residue samples were leached with pH 4.2 lixiviant. The leachates were analyzed for pH, conductivity, anions (Cl, Fl, SO_4 and alkalinity), ortho-phosphate, mercury by cold vapor atomic adsorption (CVAA) and 37 elements by ICP-MS.

4.3.4.2 Column Leach Testing

Waste Rock

Waterlab conducted dynamic column leach testing of three oxide waste rock samples. Columns were charged with 750 grams of material crushed to minus 13.2 millimeters. For each pore volume cycle, 750 milliliters of distilled water were applied to the top of the column as a trickle leach over approximately a 24-hour period. Columns were allowed to drain freely. Once fully drained, the leachate was collected for analysis and the next pore volume was applied to the top of the column. For the SD-OX and RSC-OX samples, it took approximately one day for drainage of a single pore volume. Flow through the RAT-OX column was much slower, with the time for drainage of a pore volume ranging from approximately five days at the beginning of the testing period up to approximately 30 days thereafter. In an attempt to increase the rate of flow through the RAT-OX column, the column was pressurized. Instead of increasing the rate of flow, the higher pressure resulted in compaction of the sample and a further reduction in the flow rate.

The SD-OX and RSC-OX columns were leached for 11 pore volumes. The RAT-OX column was leached for five pore volumes. Leachates were analyzed for pH, conductivity, anions (Cl, F, SO_4, alkalinity and PO_4) and 70 elements by ICP-MS.

Tailings and Ore

CEMI conducted long-term column leach testing of bench upper tailings, bulk upper ore and combined tailings samples. Tailings and ore samples (as received) were placed in a standard ASTM humidity cell. Humidity cells were constructed from acrylic tubing. Each cell had a fixed base plate with a leachate drainage hole. Approximately one inch above the base, a perforated plexi-glass plate was fitted to support the sample. The plate was covered with six layers of nylon mesh to prevent loss of fines while still allowing downward flow of leachate. Each cell was equipped with a removable lid with a central hole. Each leachate drain was equipped with a pinch valve.

The bench upper tailings and bulk upper ore humidity cells were charged with one kilogram of dry sample (the tailings cell was charged with one kilogram of equivalent dry weight sample). Due to limited sample volume, the combined tailings humidity cell was charged with 0.724 kilograms of dry sample. Samples were flood leached daily from Monday to Friday with one pore volume of water. At the end of 24 hours, column leachate was drained and collected for analysis.

To determine each sample's pore volume, 500 gram equivalent dry weight of sample was mixed with 250 milliliters of water in a one liter graduated cylinder and allowed to settle overnight. The volume of overlying water was measured and subtracted from the 250 milliliters. For the tailings sample, the initial moisture content was also subtracted. The difference represented one pore volume. For the one-kilogram samples of bench upper tailings and bulk upper ore, one pore volume was determined to be 320 milliliters and 350 milliliters, respectively. For the 0.724-kilogram sample of combined tailings, one pore volume was determined to be 485 milliliters.

The bench upper tailings sample was leached for 21 cycles. To ensure adequate sample volume, 640 milliliters (equivalent to two pore volumes) was passed through the column each cycle. All leachates were analyzed for pH and conductivity. Filtered samples from cycles 1, 2, 3, 5, 7, 9, 11, 13, 15, 17, 19 and 21 were analyzed for 37 elements by ICP-MS and mercury by CVAA. Leachates from cycles 16, 17 and 18 were also analyzed for anions (Cl, F, SO_4 and alkalinity).

The bulk upper ore sample was leached for 21 pore volumes. All leachates were analyzed for pH and conductivity. Filtered samples from pore volumes 1, 2, 3, 7, 9, 11, 13, 15, 17, 19 and 21 were analyzed for 37 elements by ICP-MS and mercury by CVAA. Leachates from these pore volumes were also analyzed for anions (Cl, F, SO_4 and alkalinity). Pore volume 1 leachate was analyzed for ortho-phosphate.

The combined tailings sample was leached for 20 pore volumes. All leachates were analyzed for pH and conductivity. Filtered samples from pore volumes 1, 3, 5, 7, 9, 11, 13, 15, 17 and 19 were analyzed for 37 elements by ICP-MS and mercury by CVAA. Leachates from these pore volumes were also analyzed for anions (Cl, F, ortho-phosphate, SO_4 and alkalinity). TDS was measured on odd numbered leachates.

4.3.5 Radioactivity

The six waste rock samples were submitted to Nuclear Energy Corporation of South Africa (NECSA) for the following solid phase analyses: gross alpha and beta activity, uranium, thorium, radium and ^{210}Pb.

CEMI subcontracted gross alpha and gross beta analysis of ore and tailings samples to the Saskatchewan Research Council of Saskatoon, Saskatchewan, Canada. Radioactivity analysis was conducted following Standard Methods for the Examination of Water and Wastewater (American Public Health Association et al. 1998).

4.4 TAILINGS SUPERNATANT WATER QUALITY

4.4.1 Tailings Neutralization and Flume Test Supernatant Sampling

Hazen provided Golder with results from the neutralization testing of the bench upper tailings. Solution chemistry was analyzed at pH 8.2, 9.0 and 10. Solutions were analyzed for a selected suite of parameters: Cu, Co, Mg, Al, Fe, Mn, Se, As, Ni, Cd, Cr, Pb, F and Hg.

The Flume O/F sample collected during flume testing of the bench upper tailings and supernatant samples collected during neutralization testing of the bench upper tailings and combined tailings were submitted to CEMI for chemical analysis.

4.4.2 Tailings Stability Test

To evaluate the stability of the neutralized tailings following atmospheric interaction, CEMI monitored the pH and conductivity of tailings slurry supernatant over a 35-day period. CEMI retained a sample of the bulk upper tailings slurry in a container open to the atmosphere. Supernatant pH and conductivity were measured on a daily basis (Monday to Friday) for a two-week period to evaluate changes in solution pH and conductivity. For weeks three to

five, the frequency of pH and conductivity measurement was decreased to weekly.

At the end of approximately five weeks, the tailings supernatant was submitted for a comprehensive chemical analysis to evaluate the potential for remobilization of constituents previously attenuated during neutralization of the tailings. The supernatant was analyzed for the following: pH, conductivity, TDS, anions (Cl, F, SO_4 and alkalinity), nutrients (ammonia, nitrate/nitrite, Kjeldahl nitrogen and ortho-phosphate), 37 elements by ICP-MS and mercury by CVAA.

5 GEOCHEMICAL CHARACTERIZATION PROGRAM RESULTS

5.1 PHYSICAL PROPERTIES

5.1.1 Particle Size Distribution

Particle size distribution curves for the waste rock, artisanal, tailing and ore samples are shown in Figure 5.1-1. The particle size distributions for the artisanal, bulk upper ore and tailings are for the as received samples. Waste rock samples were crushed to minus 13.2 millimeters for SPLP and column testing.

Figure 5.1-1 shows the particle size distribution, provided by Phelps Dodge, for the entire bulk upper ore sample (i.e., 20 tonne ore sample) as well as for the sub-sample provided to Golder for geochemical characterization (labeled as bulk upper ore). The latter was biased toward a finer particle size distribution than the sample source.

The waste rock samples have a finer particle size distribution than the ore samples. The oxide waste rock samples all reported a large percentage of fines. Between 61 and 85 percent of each sample passed the two millimeter sieve. In comparison to the waste rock and ore samples, the tailings have a more uniform particle size distribution (i.e., a steeper particle size distribution curve).

The surface area (per kilogram) of selected samples was estimated from the particle size distribution curves. Surface area was calculated assuming that each sample is comprised of spherical particles whose size distribution is defined by the particle size distribution curve. Particle size diameters were assumed to be equal to the sieve screen sizes. The sample fraction passing the smallest diameter screen was assumed to have a diameter equivalent to half the diameter of the smallest screen. Perfect packing of spherical particles was assumed (i.e., no pore space). The specific gravity of each sample was estimated from the results of the mineralogical analysis.

The estimated surface areas per kilogram for each of the oxide waste samples, the ore samples and two tailings samples (bench upper and bulk upper) are superimposed on the particle size distribution curves in Figure 5.1-1. As particle size decreases, the surface area per kilogram increases. The entire bulk upper ore sample has the lowest surface area per kilogram, estimated at 0.14 square meters per kilogram. The surface area of the upper bulk ore sample provided to Golder

is estimated to be nine square meters per kilogram, about 60 times higher than that of the entire bulk ore sample.

The surface areas of the bench upper tailings and bulk upper tailings samples are calculated to be similar, estimated at 40 and 24 square meter per kilogram, respectively. The particle size distribution curve for the combined tailings sample is bounded by the particle size distributions for the bench upper and bulk upper tailings samples. The three oxide waste rock samples have the highest surface areas, estimated to range from 77 to 355 square meter per kilogram. The high proportion of fines within each of these samples results in a high total surface area.

The surface areas presented in Figure 5.1-1 are estimates. Of most importance are the relative differences in surface area among and within sample groups (i.e., waste rock, tailings and ore) rather than the absolute values of the surface area estimates.

5.1.2 Moisture Content

The moisture contents of the bench upper tailings and bulk upper tailings were estimated at 25.9 and 26.3 percent, respectively. A similar moisture content was expected for the two samples based on their similar particle size distributions (Figure 5.1-1).

5.2 CHEMISTRY AND MINERALOGY

5.2.1 Waste Rock

Mineralogical and whole rock analysis results for the waste rock samples are presented in Tables 5.2-1 and 5.2-2, respectively. These results are for the samples collected in 2006 as part of the current program. Knight Piésold (1998) did not perform chemical or mineralogical analysis of waste rock samples.

The primary mineral phases in the six drill core waste rock samples are quartz and dolomite. Sulfide minerals were not identified at levels above the approximate method detection limit (approximately 1 percent). The mineralogical analysis results are consistent with the whole rock results in that the samples reporting the highest quartz contents also report the highest silicon concentrations and the samples reporting the highest dolomite concentrations also report the highest magnesium and calcium concentrations.

The artisanal material samples contain elevated copper carbonate concentrations (9 to 11 percent). These samples also report higher mica and chlorite concentrations than the drill core samples. Dolomite was absent in the artisanal material samples.

Table 5.2-1 Waste Rock Mineralogy (2006)

Mineral	Drill Core Samples						Artisanal Material	
	SD-OX	RSC-OX	RAT-OX	SD-S	RSC-S	RSF-S	1	2
calcite	-	-	trace	trace	-	trace	-	-
dolomite	59	20	47	55	49	64	-	-
mcguinnessite and malachite	-	-	-	-	-	-	11	9
jarosite	1	-	-	-	-	-	-	-
hematite and goethite	-	-	2	trace	-	trace	-	-
k-feldspar	1	-	5	trace	-	trace	1	1
quartz	27	75	23	26	49	29	41	42
mica	7	2	9	10	1	4	22	25
chlorite	4	2	13	8	1	2	24	22
illite/smectite interstratification	1	1	1	1	-	1	1	1
Total	100	100	100	100	100	100	100	100

Mineralogical analysis by X-ray diffraction (XRD). Percentage (%) of each mineral phase shown.

Table 5.2-2 Waste Rock Whole Rock Chemistry Results (2006)

	Unit	Drill Core Samples						Artisanal Material	
		SD-OX	RSC-OX	RAT-OX	SD-S	RSC-S	RSF-S	1	2
SiO_2	wt. %	40.19	75.18	54.64	44.17	53.30	46.49	44.33	50.60
TiO_2	wt. %	0.31	0.14	0.86	0.43	0.07	0.22	0.74	0.79
Al_2O_3	wt. %	6.26	2.10	11.88	7.30	0.91	3.19	13.14	15.67
Fe_2O_3(t)	wt. %	2.15	0.87	5.01	2.85	0.60	1.34	2.14	1.59
MnO	wt. %	0.057	0.050	0.061	0.057	0.039	0.046	0.062	0.022
MgO	wt. %	12.32	5.38	9.36	12.11	9.96	11.29	10.58	9.37
CaO	wt. %	13.87	5.94	4.27	11.44	13.67	14.17	0.07	0.05
Na_2O	wt. %	<0.01	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	<0.01
K_2O	wt. %	1.390	0.270	2.790	1.300	0.060	0.500	1.520	2.450
P_2O_5	wt. %	0.073	0.047	0.118	0.119	0.033	0.074	<0.01	0.158
Cr_2O_3	wt. %	0.007	0.004	0.012	0.010	0.003	0.006	0.017	0.018
L.O.I.	wt. %	22.94	9.80	10.08	19.37	21.23	20.94	8.73	6.83
TOTAL	wt. %	99.57	99.77	99.14	99.14	99.85	98.26	81.32	87.54
H_2O	wt. %	0.17	0.13	0.20	0.65	0.15	0.20	4.63	2.09

Analysis by X-ray fluorescence spectrometry (XRF)
L.O.I - loss on ignition

Trace metal analysis results are shown in Table 5.2-3. The artisanal material samples were only analyzed for a few trace metals. The trace-metal content of each rock type was evaluated to identify potential metals of concern, although it should be understood that a high concentration of a particular element does not necessary imply that this element will indeed be mobilized in concentrations that may lead to environmental impacts. For reference, Table 5.2-3 includes the average abundance of each element in the earth's crust (Smith and Huyck 1999).

The copper concentrations of the six drill core waste rock samples ranged from 423 to 7,534 parts per million (i.e., 0.04 to 0.7 weight percent). The copper contents of the two artisanal material samples were much higher at 135,200 and 63,200 parts per million (13.52 and 6.32 weight percent). Due to their highly elevated copper concentrations, these samples are likely more representative of ore than waste rock. Mineralogical analysis identified malachite [$Cu_2(CO_3)(OH)_2$] as the primary copper bearing mineral phase in the artisanal samples (see Table 5.2-1). Copper is therefore present in a fairly labile form. Other copper-bearing minerals include chrysocolla, which occurs in moderate (less than 2 to 8 percent) to minor amounts, as well as copper minerals present in minor to trace amounts such as pseudomalachite, libethenite, native copper with cuprite oxidation, tenorite, chalcopyrite, chalcocite, covellite and bornite (Baum et al. 2006). However, due to their low concentrations, none were identified by XRD.

The cobalt concentrations of the six drill core waste rock samples ranged from 211 to 2,997 parts per million (i.e., 0.02 to 0.3 weight percent). The sulfide waste rock samples generally reported higher cobalt concentrations than the oxide ore samples. The cobalt contents of the two artisanal material samples were much higher at 29,700 and 19,300 parts per million (2.97 and 1.93 weight percent). Due to their highly elevated cobalt concentrations, these samples are likely more representative of ore than waste rock. Despite cobalt concentrations of a few weight percent, mineralogical analysis did not identify any discrete cobalt bearing minerals. The major source for cobalt is heterogenite, which is a hydrated cobalt oxide which may contain significant amounts of Cu, Fe, Mn and other impurities. In addition, cobalt is ubiquitously present in iron oxides/hydroxides and occurs in malachite, chrysocolla and other copper minerals due to alteration and replacement (Baum et al. 2006).

In addition to copper and cobalt, the following elements were higher than average crustal abundance in one or more samples: arsenic (As), bromide (Br), cerium (Ce), cesium (Cs), molybdenum (Mo), neodymium (Nd), selenium (Se), thorium (Th), thallium (Tl), uranium (U) and zirconium (Zr).

Table 5.2-3 Waste Rock Trace Metal Results (2006)

	Unit	Crustal Abundance[(a)]	Drill Core Samples						Artisanal Material	
			SD-OX	RSC-OX	RAT-OX	SD-S	RSC-S	RSF-S	1	2
As	ppm	2	**10.0**	<4	**4.2**	**12.0**	<4	**10.0**		
Ba	ppm	430	117	80	395	149	172	191		
Bi	ppm	0.2	<3	<3	<3	<3	<3	**3.5**		
Br	ppm	3	**4.7**	**3.8**	2.2	2.9	**4.7**	**3.2**	-	-
Ce	ppm	45	36	15	**79**	15	<10	42	-	-
Co	ppm	25	**211**	**1,523**	**401**	**1,720**	**1,019**	**2,997**	**29,700**	**19,300**
Cr	ppm	200	37	14	69	51	10	24	-	-
Cs	ppm	3	**7.8**	<5	<5	<5	**6.5**	**10.0**	-	-
Cu	ppm	60	**423**	**1,596**	**3,161**	**4,568**	**710**	**7,534**	**135,200**	**63,200**
Ga	ppm	17	8.1	2.9	17.0	10.0	1.0	4.3	-	-
Ge	ppm	15	1.1	<1	<1	<1	<1	<1	-	-
Hf	ppm	-	<3	<3	6.5	<3	<3	<3	-	-
La	ppm	*6.5 - 100*	18	<10	45	12	<10	20	-	-
Mo	ppm	2	**4.0**	<2	**2.5**	**2.1**	<2	**2.3**	-	-
Nb	ppm	20	6.0	2.5	17.0	8.2	1.6	4.0	-	-
Nd	ppm	25	15	<10	**32**	<10	<10	16	-	-
Ni	ppm	80	9.2	6.6	37.0	46.0	4.3	4.6	-	-
Pb	ppm	16	6.9	<2	3.7	5.2	<2	2.4	-	-
Rb	ppm	120	46	10	90	51	5	20	-	80
Sc	ppm	*5 - 22*	11	6	15	15	9	12	-	-
Se	ppm	0.09	<1	<1	<1	<1	**1.5**	**1.6**	-	-
Sm	ppm	7	<10	<10	<10	<10	<10	<10	-	-
Sr	ppm	350	87	41	91	56	46	51	-	120
Ta	ppm	2	<2	<2	<2	<2	<2	<2	-	-
Th	ppm	10	5.2	<3	**11.0**	6.6	<3	4.2	-	-
Tl	ppm	1	<3	<3	<3	**3.0**	<3	**4.0**	-	-
U	ppm	3	3.0	<2	**11.0**	**6.1**	<2	**3.7**	-	-
V	ppm	150	65	25	104	88	13	56	-	-
W	ppm	1	<3	<3	<3	<3	<3	<3	-	-
Y	ppm	30	12	5	29	11	4.6	7	-	-
Yb	ppm	3	<2	<2	<2	<2	<2	<2	-	-
Zn	ppm	70	19	9	32	18	6	10	-	-
Zr	ppm	160	82	36	**249**	109	15	52	**300**	90

[(a)] Smith and Huyck (1999). Approximate consensus values from presented when available. Italics identify consensus range when approximate value not available.

Bolded values identify exceedances of crustal abundance.

Arsenic was present in both the oxide and sulfide waste samples. The source of arsenic in these samples may be erythrite [$Co_3(AsO_4)2{\bullet}8H_2O$], one of the cobalt bearing minerals. The presence of erythrite was not be confirmed by

mineralogical analysis. Molybdenum and uranium were also detected in both oxide and sulfide waste rock samples. Selenium and thallium were only detected in the sulfide waste samples.

Nickel is present in the ore mineral carrolite [$Cu(Co,Ni)_2S_4$]. Nickel concentrations in the six waste rock samples ranged from 4.3 to 46 parts per million, all below the average crustal abundance concentration of 80 parts per million.

5.2.2 Tailings and Ore

Mineralogical and elemental analysis results for the tailings and ore sample are presented in Tables 5.2-4 and 5.2-5, respectively. For reference, Table 5.2-5 includes the average abundance of each element in the earth's crust (Smith and Huyck 1999). Comparison of tailings results to crustal abundance is included for consistency; however, because tailings are not a natural material, this comparison is less relevant than the comparison of the ore and waste rock concentrations to crustal abundance. Whole rock analysis results for the bulk upper tailings are presented in Table 5.2-6.

Table 5.2-4 Tailings and Ore Mineralogy (2006)

Mineral	Tailings (Bench Upper) [(a)]	Ore (Bulk Upper)[(a)]	Tailings (Bulk Upper)[(b)]	Tailings (Combined)[(a)]
Quartz	40.9	37.6	significant (>50%)	68.2
Clinochlore	20.7	13.6	-	10.3
Chlorite	-	-	moderate (10-15%)	-
Muscovite	33.4	38.9	moderate (10-20%) [(c)]	8.7
Malachite	-	3.2	-	-
Plagioclase	2.7	-	-	-
Hematite	0.6	-	-	0.5
Goethite	0.4	0.3	-	0.4
Calcite	0.6	-	minor (5%)	-
Rutile	0.7	1	-	-
Tourmaline (?)[(d)]	-	5.4	-	-
Dravite (?)[(d)]	-	-	-	8.3
Gypsum	-	-	-	2.2
K-Feldspar	-	-	-	1.4
Total	100	100	-	100

(a) Quantitative phase analysis by the Rietveld method. Percentage (%) of each mineral phase shown.

(b) Qualitative analysis results. Approximate percentage (%) of each mineral phase shown.

(c) Analysis identified mica with muscovite listed as the most probable mineral.

(d) Question marks reported by the lab indicate some uncertainty in mineral identification.

Table 5.2-5 Tailings and Ore Elemental Analysis Results (2006)

Element	Units	Crustal Abundance[(a)]	Tailings (Bench Upper)	Ore (Bulk Upper)	Tailings (Bulk Upper)	Tailings (Combined)	Tailings (FAM Solids)
Ag	ppb	70	**321**	**227**	**148**	**516**	23
Al	%	8	2.42	2.19	1.04	1.01	0.27
As	ppm	2	**10.3**	**13.3**	**9**	**7.4**	**15.1**
Au	ppb	4	3.2	0.5	6	2.5	0.3
B	ppm	10	4	8	<1	2	<1
Ba	ppm	430	23.2	28.7	13.3	21.1	3.2
Bi	ppm	0.2	**20.67**	**7.91**	**7.91**	**14.16**	**0.49**
Ca	%	3	0.12	0.02	3.68	0.54	11.57
Cd	ppm	0.18	<0.01	<0.01	<0.01	0.03	0.02
Co	ppm	25	**474.6**	**>2000**	**297.9**	**490.6**	**410.2**
Cr	ppm	200	61.3	70.1	20.4	35	16.8
Cu	ppm	60	**701.42**	**>10000**	**789.94**	**1,557.57**	**2,930.49**
Fe	%	5	1.55	1.26	1.01	1.22	0.62
Ga	ppm	17	5.1	5.4	2.3	2.6	0.6
Hg	ppb	80	23	13	21	37	<5
K	%	2.6	0.11	0.38	0.04	0.03	<0.01
La	ppm	*6.5 - 100*	27.9	51	12.9	7.4	3.2
Mg	%	2.1	**3.32**	**2.79**	1.63	1.66	0.24
Mn	ppm	900	76	126	33	50	**2,136**
Mo	ppm	2	**4.88**	**2.99**	**3.61**	**6.53**	1.03
Na	%	2.4	0.003	0.005	0.003	0.006	0.002
Ni	ppm	80	14.7	26.6	9.7	20.3	4.2
P	%	0.1	0.006	0.063	0.015	0.017	**0.33**
Pb	ppm	16	4.9	4.16	3.34	3.58	7.15
S	%	0.05	0.02	0.01	0.03	**0.43**	**9.41**
Sb	ppm	*0.15 - 1*	**1.41**	0.62	**1.18**	0.67	0.21
Sc	ppm	5 - 22	2	3.6	1.6	3.5	7.3
Se	ppm	0.09	**0.1**	**1.5**	**0.1**	**0.4**	**0.3**
Sr	ppm	350	6.8	13.7	143.1	12.3	**402.6**
Te	ppm	*0.00036 - 0.01*	**0.02**	**0.05**	<0.02	<0.02	<0.02
Th	ppm	10	3.2	5.3	2.0	1.8	0.6
Ti	%	0.5	0.002	0.002	0.002	0.002	0.002
Tl	ppm	1	0.04	0.07	0.04	0.06	0.07
U	ppm	3	1.1	**4.4**	1.1	2.1	**12.5**
V	ppm	150	31	59	27	37	94
W	ppm	1	0.9	<0.1	<0.1	<0.1	<0.1
Zn	ppm	70	15.9	22.2	11.8	8.4	3.1

[(a)] Smith and Huyck (1999). Approximate consensus values from presented when available. Italics identify consensus range when approximate value not available.

Bolded values identify exceedances of crustal abundance.

Table 5.2-6 Tailings Whole Rock Chemistry Results

Parameter	Units	Tailings (Bulk Upper)	Tailings (Combined)	Tailings (FAM Solids)
SiO_2	wt. %	59.14	76.93	3.08
TiO_2	wt. %	0.88	0.54	0.02
Al_2O_3	wt. %	15.1	8.27	1.01
Fe_2O_3	wt. %	2.26	2.03	1.01
MnO	wt. %	0.01	0.02	0.29
MgO	wt. %	6.12	4.27	0.48
CaO	wt. %	4.24	0.88	29.82
Na_2O	wt. %	0.03	0.06	0.48
K_2O	wt. %	3.59	1.32	0.03
P_20_5	wt. %	0.08	0.02	0.67
Ba	wt. %	0.02	0.02	0.02
L.O.I[(a)]	wt. %	7.43	4.27	23.33
Total	**wt. %**	**98.9**	**98.62**	**60.24**

[(a)] L.O.I. – loss on ignition.
wt. % = weight percent

Quartz and muscovite are the primary mineral phases in the tailings and ore samples. The bulk upper ore sample contained 3.2 percent malachite. Calcite was present at up to approximately five percent in the neutralized tailings. Gypsum was present in the combined tailings, attributable to the presence of the $Mg(OH)_2$ waste.

Cobalt and copper concentrations in the upper bulk ore sample were above the analytical reporting limits of 2,000 and 10,000 parts per million, respectively. The cobalt and copper contents of the bench upper tailings and bulk upper tailings were similar, with cobalt concentrations ranging from 300 to 475 parts per million and copper concentrations ranging from 700 to 790 parts per million. The combined tailings and FAM solids reported higher copper concentrations than the bench and bulk upper tailings (1,558 and 2,930 parts per million, respectively). Combined tailings and FAM solids cobalt concentrations were similar to the bulk upper tailings at 491 and 410 parts per million, respectively.

The following elements reported concentrations higher than average crustal abundance in the ore sample: silver (Ag), arsenic (As), bismuth (Bi), cobalt (Co), copper (Cu), magnesium (Mg), molybdenum (Mo), selenium (Se), tellurium (Te) and uranium (U).

Elemental concentrations for the bench upper tailings and bulk upper tailings sample were generally similar. The bulk upper tailings sample reported a higher

calcium content, likely due to greater lime addition during neutralization of this sample compared to the bench upper tailings sample (i.e., the bulk upper tailings sample was neutralized to pH ~9 whereas the bench upper tailings sample was neutralized to pH ~7). Mineralogical analysis indicated a higher calcite content for the bulk upper tailings sample than the bulk upper tailings sample. The strontium content of the bulk upper tailings sample was also much higher than the concentration in the bench upper tailings sample.

The combined tailings and FAM samples, generated in the latter stages of the metallurgical testing program, are considered most representative of the tailings that will be produced during mineral processing. The trace metal contents of these samples were compared to those of the other tailings samples (bulk upper and bench upper) to identify possible differences in their chemical composition. For the following metals, the combined tailing sample reported higher concentrations than the other tailings samples: Ag, Hg, Mo, Ni and Se. It should be understood that a high concentration of a particular element does not necessary imply that this element will indeed be mobilized in concentrations that may lead to environmental impacts. As will be discussed in Section 5.4.2.1, SPLP leachate concentrations for Ag, Hg, Mo and Ni were similar for all tailings samples. Selenium leachate concentrations for the combined tailing sample (which were low at 0.0024 milligrams per liter) were higher than for the other tailings samples (Table 5.4-9). In comparison to the three tailings samples, the FAM solids reported elevated manganese and mercury. SPLP testing of the FAM solids indicated slightly higher manganese leaching in comparison to the other tailings samples; however, consistent with the other tailings samples, mercury concentrations were below detectable limits. Iron and aluminum concentrations were not elevated relative to the other tailings samples.

In addition to copper and cobalt, concentrations of a number of trace metals were lower in the bulk upper tailings sample than the bulk upper ore sample (e.g., Ag, As, Cr, Mn, Ni, Se, U and Zn). Mobilization and leaching of these metals during processing likely explains the observed depletion in metal concentrations for the bulk upper tailings sample versus the ore sample.

5.3 ACID GENERATION POTENTIAL

A number of criteria have been proposed for assigning an ARD potential to a material using ABA results. The most common approaches are those based on use of the neutralization potential ratio (NPR = NP/AP) and the net neutralization potential (NNP = NP - AP). For several reasons, no single ratio or NNP value has been identified to have universal applicability in terms of predicting acid generation. The actual threshold values for a particular solid are material-specific, and depend on many factors, including the amounts and types of acid

generating and neutralizing minerals, their morphology, their grain size, their crystallinity, their chemical composition, their paragenesis, the material's texture, and the site-specific exposure conditions.

NPR guidelines presented by Price (1997) are summarized in Table 5.3-1 below. These guidelines were applied in the evaluation of ABA results.

Table 5.3-1 ABA Screening Guidelines for ARD Potential (Price 1997)

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

5.3.1 Waste Rock

ABA results for all waste rock samples are shown in Table 5.3-2. The total sulfur content of all oxide waste rock samples was low, ranging from below detectable limits (less than 0.01 weight percent) to 0.11 weight percent. Greater than 85 percent of samples reported total sulfur values equal to or less than 0.02 weight percent. The three sulfide waste rock samples reported total sulfur contents ranging from 0.04 (RSC-S) to 0.70 weight percent (RSF-S).

Table 5.3-2 Waste Rock ABA and NAG pH Results

Data Source	Lithology	Composite Sample ID	Paste pH	Fizz Rate	NP	AP	NNP	NPR	S(T)	$S(S^{-2})$	$S(SO_4)$	TIC	CaNP	NAG pH
			s.u.		kg $CaCO_3$/t				wt. %			% CO_3	kg $CaCO_3$/t	s.u.
SD - Oxide Waste Rock														
KP	SDS-OX	21100	8.67	2	293	0.31	293	945	<0.01	<0.01	<0.4	18.7	310	-
KP	SDS-OX	21000	7.59	2	114	0.31	114	368	<0.01	<0.01	<0.4	7.2	120	-
KP	SDS-OX	20800-20700	8.99	3	544	0.31	544	1755	0.03	0.01	<0.4	32.3	536	-
KP	SDS-OX	20500	8.73	2	402	0.31	402	1297	<0.01	<0.01	<0.4	24.1	400	-
KP	SDS-OX	20400	8.57	3	438	0.31	438	1413	0.01	<0.01	<0.4	26.6	442	-
KP	SDS-OX	20300-20200	8.96	2	246	0.31	246	794	0.01	<0.01	<0.4	14.1	234	-
KP	SDS-OX	20100	8.37	2	489	0.31	489	1577	<0.01	<0.01	<0.4	28.5	473	-
Golder	SD-OX		8.79	-	254	0.13	254	2030	0.005	0.004	0.001	-	-	5.78
RSC - Oxide Waste Rock														
KP	RSC-OX	21100-21000	9.04	2	305	0.31	305	984	0.02	<0.01	<0.4	18.4	305	-
KP	RSC-OX	20800	7.66	1	5.6	0.31	5.3	18	0.02	<0.01	<0.4	0.55	9	-
KP	RSC-OX	20500-20300	8.91	2	134	0.31	134	432	0.02	<0.01	<0.4	7.85	130	-
KP	RSC-OX	20200	8.35	1	14.1	0.31	14	45	0.01	<0.01	<0.4	1.05	17	-
KP	RSC-OX	20100	9.10	2	22.2	0.31	22	72	<0.01	<0.01	<0.4	1.05	17	-
KP	RSC-OX	20000-19900	8.44	2	47.3	0.31	47	153	0.01	<0.01	<0.4	3.15	52	-
KP	RSC-OX	19800-19600	8.72	3	51.8	0.31	51	167	0.02	<0.01	<0.04	13.8	229	-
Golder	RSC-OX		9.04	-	144	0.41	143	354	0.015	0.013	0.002	-	-	7.69
RAT - Oxide Waste Rock														
KP	RAT-OX	21100-20800	8.07	1	9.1	0.31	8.8	29	<0.01	<0.01	<0.4	1.05	17	-
KP	RAT-OX	20500-20400	8.37	1	69.7	0.31	69	225	0.04	<0.01	<0.4	4.2	70	-
KP	RAT-OX	20300	8.69	1	19	0.31	19	61	0.11	<0.01	<0.4	0.85	14	-
KP	RAT-OX	20200	8.32	1	54.7	0.31	54	176	<0.01	<0.01	<0.4	3.25	54	-
KP	RAT-OX	20100	7.84	1	11.1	0.31	11	36	<0.01	<0.01	<0.4	0.4	7	-

Table 5.3-2 Waste Rock ABA and NAG pH Results (continued)

Data Source	Lithology	Composite Sample ID	Paste pH	Fizz Rate	NP	AP	NNP	NPR	S(T)	$S(S^{-2})$	$S(SO_4)$	TIC	CaNP	NAG pH
			s.u.		kg $CaCO_3$/t				wt. %			% CO_3	kg $CaCO_3$/t	s.u.
KP	RAT-OX	20000	7.13	1	10.4	0.31	10	34	0.01	<0.01	<0.4	0.65	11	-
KP	RAT-OX	19900 - 19600	8.19	2	199	0.31	199	642	0.01	<0.01	<0.4	11.7	194	-
Golder	RAT-OX		8.55	-	144	0.44	143	329	0.017	0.014	0.003	-	-	6.53
SD, RSC and RSF - Sulfide Waste Rock														
Golder	SD-S		8.70	-	368	3.69	364	100	0.123	0.118	0.005	-	-	7.50
Golder	RSC-S		9.08	-	254	1.2	253	209	0.043	0.039	0.004	-	-	7.52
Golder	RSF-S		9.13	-	376	21.1	355	18	0.688	0.676	0.012	-	-	7.49
Historical Artisanal Mining Material														
Golder	1		8.16	-	200	0.88	199	229	0.032	0.028	0.004	-	-	7.35
Golder	2		8.41	-	75	0.28	75	267	0.012	0.009	0.003	-	-	7.26

AP = Acid Generation Potential.

NP = Neutralization Potential.

NNP = Net Neutralization Potential (NP-AP).

NPR = Neutralization Potential Ratio (NPR = NP/AP).

TIC = total Inorganic Carbon.

Data Source: KP - Knight Piésold (1998), Golder (current study).

Replicate Knight Piésold samples omitted.

NPR value for SDS-20500 reported as 1577 kg $CaCO_3$/t in Knight Piésold (1998) report. Corrected to 1297 kg $CaCO_3$/t in above table.

Total sulfur versus paste pH is shown in Figure 5.3-1. Paste pH values for all waste rock samples were neutral to alkaline, ranging from 7.1 to 9.1. The higher end paste pH values likely represent equilibrium with dolomite. Price (1997) reports an abrasion pH of 9 to 10 for dolomite. The RAT oxide samples generally reported the lowest paste pH values.

The neutralization potentials (NP) of the oxide waste rock samples range from 5.6 to 544 kilograms $CaCO_3$ per tonne. The SD samples reported the highest NP values, consistent with the higher dolomite content of this lithology. Average NPs for the three oxide lithologies are as follows: SD (347 kilograms $CaCO_3$ per tonne), RSC (90 kilograms $CaCO_3$ per tonne) and RAT (65 kilograms $CaCO_3$ per tonne).

Knight Piésold (1998) measured the inorganic carbon content of the oxide waste rock samples. Figure 5.3-2 shows the relationship between NP and carbonate NP (CaNP). The strong correlation between NP and CaNP indicates that the NP of the waste can be attributed to the presence of carbonates (i.e., dolomite and to a lesser degree calcite based on the results of mineralogical analysis) and therefore is considered readily available.

NP versus AP is shown in Figure 5.3-3. The Price threshold NPR criteria of 1, 2 and 4 are superimposed on this figure. All waste rock samples (i.e., oxide and sulfide) report NPR values greater than four and are therefore classified as having no acid generation potential.

Evaluation of the NNP values also indicates adequate neutralization potential. A negative NNP indicates a general potential to generate acidic drainage whereas a positive NNP represents a propensity to neutralize any acid generated by the rock or mining waste. All waste rock samples reported a positive NNP (Figure 5.3-4).

The results of NAG testing also indicate no ARD potential. NNP versus NAG pH is shown in Figure 5.3-5. All waste rock samples reported NAG pH values of greater than 4.5 and positive NNP values. The NAG results therefore provide additional confirmation that the waste rock samples are non acid generating.

In summary, the oxide waste rock samples are classified as having no potential to generate acidity based on the following:

- The total sulfur contents, and therefore AP, of all samples are low.
- All samples reported NPR values greater than 4.
- All samples reported positive NNP values.

- Dolomite is identified as the primary source of NP and therefore NP should be readily available.
- All samples reported near neutral NAG pH values.

Results for the three sulfide waste rock samples also indicate no potential to generate acidity due to adequate NP; however, the data set for this rock type is limited to only three samples. Therefore, if mining is anticipated to encounter sulfide zones, additional testing would be required to better characterize the ARD potential of the deeper material.

5.3.2 Tailings and Ore

ABA results for the tailings and ore samples are shown in Table 5.3-3.

Table 5.3-3 Ore and Tailing ABA and NAG pH Results

Parameter	Units	Tailings (Bench Upper)	Ore (Bulk Upper)	Tailings (Bulk Upper)	Tailings (Combined)	Tailings (FAM Solids)
Paste pH	s.u.	7.94	8.49	8.24	8.8	6.6
S(T)	wt. %	0.05	0.04	0.04	0.44	10.1
$S(SO_4)$	wt. %	<0.01	<0.01	0.02	0.36	9.68
$S(S^{-2})$	wt. %	0.05	0.04	0.02	0.04	0.02
TIC	wt. %	-	-	0.61	<0.01	0.12
AP	kg $CaCO_3$/t	1.6	1.3	0.63	1.3	0.6
NP	kg $CaCO_3$/t	8.1	47	54	55	66
CaNP	kg $CaCO_3$/t	-	-	51	<0.8	10.0
NNP	kg $CaCO_3$/t	6.5	45	53	54	65
NPR		5.2	37	86	105	44
Fizz Test		none	moderate	moderate	none	none
NAG pH	s.u.	7.53	7.88	-	7.40	6.71

AP = Acid Generation Potential (determined from calculated sulfide sulfur content: S(T) - $S(SO_4)$).
NP = Neutralization Potential, CaNP = Carbonate Neutralization Potential.
NNP = Net Neutralization Potential (NNP = NP – AP).
NPR = Neutralization Potential Ratio (NPR = NP/AP).
TIC – Total Inorganic Carbon.
wt. % = weight percent
s.u. = standard unit

The total sulfur contents of the ore and bench upper and bulk upper tailings were very low, ranging from 0.04 to 0.05 weight percent, respectively (Figure 5.3-1). Sulfide was the dominant form of sulfur. The combined tailings and FAM solids reported total sulfur contents of 0.44 and 10.1 weight percent, respectively. Sulfate was the dominant form of sulfur in both samples (likely present as gypsum).

The bulk upper ore sample reported an NP of 47 kilograms $CaCO_3$ per tonne. The NP values of the bench upper tailings and bulk upper tailings samples were 8.1 and 54 kilograms $CaCO_3$ per tonne, respectively. Although dolomite will be leached from the ore during processing, NP is added back to the tailings during neutralization. The higher NP for the bulk upper tailings relative to the bench upper tailings is consistent with its higher calcite content and neutralization to a higher pH value (i.e., ~9 for the bulk upper tailings as compared to ~7 for the bench upper tailings). The NP of the combined tailings was 55 kilograms $CaCO_3$ per tonne, similar to that of the bulk upper tailings. The target neutralization pH for the combined tailings was similar to that of the bulk upper tailings (i.e.,~10 and 9 for the combined and bulk upper tailings, respectively). However, the TIC content of the combined tailings sample was non-detect, resulting in no measurable CaNP (Figure 5.3-2).

The NP of the FAM solids at 66 kilograms $CaCO_3$ per tonne was higher than that of the other tailings samples. The FAM will be neutralized to pH 3.5 with limestone (Section A4). The paste pH of the FAM solids sample (6.6) suggests that the FAM sample analyzed may have had excess limestone addition.

The ore and tailings are classified as non acid generating based on the following:

- The sulfide contents (and therefore AP) of the ore and tailings are low.
- The NPR values for the ore and tailings are greater than four (Figure 5.3-3).
- The NNP values for the ore and tailings are positive (Figure 5.3-4).
- The NAG pH values for the ore and tailings were near neutral ranging from 7.4 to 7.9 (Figure 5.3-5).

5.4 METAL LEACHING POTENTIAL

Results from three types of leach tests were available to assess metal leaching from waste rock, ore and tailings: SPLP, NAG and column leach test. Table 5.4-1 summarizes the details of each of these tests. Variability in the solution to solid ratio, lixiviant, reaction time and sample particle size reduction

must all be considered in the evaluation and comparison of leach test results. For waste rock, tailings and ore, results from each type of leach test are discussed separately followed by an overall evaluation of metal leaching potential based on all test results.

5.4.1 Waste Rock

5.4.1.1 SPLP Leach Test Results

SPLP leach test results from the Knight Piésold (1998) and the current Golder testing programs are shown in Tables 5.4-2 and 5.4-3, respectively.

SPLP leachate pH values for the 1998 data set ranged from 6.4 to 9.8. The 2006 samples consistently reported leachate pH values at the low end of this range (i.e. pH values for the 2006 samples ranged from 6.2 to 6.5). The artisanal material samples reported the lowest pH values (5.6 to 5.8). SPLP vs. paste pH values for all waste rock samples are shown in Figure 5.4-1. Although the 2006 samples consistently reported lower pH values for SPLP leachates, their range was at the high end of paste pH values reported for the 1998 data set. Because the mobility of many metals increases as pH decreases, the 2006 samples typically reported higher SPLP leachate metal concentrations indicating greater metal leaching potential for waste rock.

As discussed in Section 4, the 2006 geochemical waste rock testing program was intended to verify the geochemical characterization data compiled by Knight Piésold. The observed differences in metal leaching, attributed in part to lower SPLP leachate pH values, represent a fundamental and consistent difference between the two data sets. The observed differences may be attributable to variability in sample particle size distribution, and therefore reactive surface area.

The SPLP protocol stipulates that samples must pass a 9.5 millimeter sieve or have a surface area greater than 3.1 square centimeters per gram. The Knight Piésold report indicates that the standard protocol was followed. Particle size distribution curves for the three 2006 oxide waste rock samples are shown in Figure 5.1-1. These samples were crushed to 100 percent passing a 13.2 millimeter sieve. All three samples reported a large percentage of fines, with between 61 and 85 percent of the each sample passing the two millimeter sieve. A high percentage of fines results in a high surface area. Because particle size distribution data are not available for the 1998 data set, possible differences in surface area between the 1998 and 2006 testing program cannot be evaluated. It can therefore only be speculated that the observed differences are due to differences in reactive surface area.

Table 5.4-1 Summary of Leach Test Details

	Knight Piésold	Current Study						
	Waste Rock	**Waste Rock**	**Artisanal Material**	**Tailings (Bench Upper)**	**Tailings (Bulk Upper)**	**Tailings (Combined)**	**Tailings (FAM Solids)**	**Ore (Bulk Upper)**
synthetic precipitation leaching procedure (SPLP)								
solution (mL)	1000	1000	1000	1000	1000	1000		1000
solid (g)	20	20	20	20	20	20		20
solution : solid	20 : 1	20 : 1	20 : 1	20 : 1	20 : 1	20 : 1	20 : 1	20 : 1
particle size	< 9.5 mm	< 13.2 mm	as received	as received	as received	as received	as received	as received
lixiviant	pH 4.2	pH 4.2	pH 4.2	pH 6.2 (1) pH 4.2 (2)	pH 6.2 (1) pH 4.2 (2)	pH 4.2	pH 4.2	pH 4.2
reaction time (hours)	18	18	18	18	18	18	18	18
net acid generation (NAG)								
solution (mL)	-	250	250	250	250	-	-	250
solid (g)	-	2.5	2.5	2.5	2.5	-	-	2.5
solution : solid	-	100 : 1	100 : 1	100 : 1	100 : 1	-	-	100 : 1
particle size	-	pulverized	pulverized	pulverized	pulverized	-	-	pulverized
lixiviant		15% H_2O_2	15% H_2O_2	15% H_2O_2	15% H_2O_2	-	-	15% H_2O_2
reaction time (hours)		variable	variable	variable	variable	-	-	variable
column								
solution (mL)	-	750	-	640	-	485	-	700 (pore volume 1) 350 (pore volumes 2 to 21)
solid (g)	-	750	-	1000	-	724	-	1000
solution : solid	-	1 : 1	-	0.64 : 1	-	0.67 : 1	-	0.35 : 1
particle size	-	< 13.2 mm	-	as received	-	as received	-	as received
lixiviant	-	distilled water	-	distilled water	-	distilled water	-	distilled water
reaction time (hours)	-	~24 (trickle leach) (SD and RSC) [a]	-	~24 (flood leach)		~24 (flood leach)	-	~24 (flood leach)

(a) Residence time for the RAT-OX was on the order of days (i.e., approximately 1 to 30 days).

Table 5.4-2 Waste Rock SPLP Leach Test Results (1998)

Lithology	Composite Sample ID	Final pH	Cond.	Alkalinity	TDS	F	Cl	NO_2	NO_3	PO_4	SO_4	Hg	Ag	Al	As	Ba	Be	Ca	Cd	Co	Cu	Cr	Fe	K	Mg	Mn	Na	Ni	Pb	Sb	Se	Tl	Zn
		s.u.	µS/cm	mg/L as $CaCO_3$	mg/L	mg/L	mg/L	mg/L-N	mg/L-N	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
SDS	21100	9.23	170	52	108	0.96	8.8	<0.06	0.42	<0.3	11	0.0002	<0.003	0.17	<0.001	0.004	<0.001	12.1	<0.002	<0.004	0.017	<0.004	<0.003	11.7	6.94	0.001	2.27	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
SDS	21000	7.8	92	34	70	0.33	2.3	<0.06	0.46	<0.3	7.6	<0.0001	<0.003	0.04	0.005	<0.002	<0.001	6.53	<0.002	<0.004	0.024	<0.004	<0.003	2.2	5.14	0.003	1.35	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
SDS	20800-20700	9.37	194	57	110	0.61	11	<0.06	0.58	<0.3	15	<0.0001	<0.003	0.08	<0.001	0.013	<0.001	13.7	<0.002	<0.004	0.012	<0.004	<0.003	8.29	10.1	0.001	2.33	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
SDS	20500	8.53	134	48	56	0.20	5.8	<0.06	0.58	<0.3	11	<0.0001	<0.003	0.04	0.007	0.005	<0.001	13.6	<0.002	<0.004	0.028	<0.004	<0.003	3.9	5.13	<0.001	1.47	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
SDS	20400	9.39	102	33	94	0.15	2.5	<0.06	0.51	<0.3	8.2	<0.0001	<0.003	<0.02	<0.01	0.003	<0.001	9.23	<0.002	<0.004	0.015	<0.004	<0.003	2	4.85	<0.001	1.68	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
SDS	20300-20200	9.35	68	34	50	0.13	1.4	<0.06	0.30	<0.3	4.4	<0.0001	<0.003	<0.02	<0.01	0.063	<0.001	5.81	<0.002	<0.004	0.005	<0.004	<0.003	2.02	3.83	<0.001	0.38	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
SDS	20100	8.49	94	41	44	0.45	3.3	<0.06	0.16	<0.3	3.8	<0.0001	<0.003	0.03	0.001	<0.002	<0.001	7.75	<0.002	<0.004	0.004	<0.004	<0.003	1.82	5.35	<0.001	0.75	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RSC	21100-21000	9.76	78	27	56	0.04	2.4	<0.06	0.23	<0.3	5.7	<0.0001	<0.003	<0.02	<0.01	0.016	<0.001	7.21	<0.002	<0.004	<0.003	<0.004	<0.003	1.14	3.85	<0.001	0.65	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RSC	20800	9.58	70	22	52	0.07	2.8	<0.06	0.25	<0.3	5.7	<0.0001	<0.003	<0.02	<0.01	0.093	0.001	6.86	<0.002	<0.004	<0.003	<0.004	<0.003	1.14	3.53	<0.001	0.58	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RSC	20500-20300	7.19	44	7	40	0.08	2.1	<0.06	0.40	<0.3	7.2	<0.0001	<0.003	0.12	<0.01	0.023	<0.001	3.55	<0.002	0.24	0.083	<0.004	0.056	1.34	1.68	0.26	0.37	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RSC	20200	7.43	54	11	58	0.11	4.6	<0.06	0.10	<0.3	6.3	<0.0001	<0.003	<0.02	<0.001	<0.002	<0.001	2.63	<0.002	0.016	0.02	<0.004	<0.003	2.39	1.98	0.003	2.03	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RSC	20100	9.56	145	22	90	0.36	16	<0.06	0.25	<0.3	16	0.0002	<0.003	0.34	0.006	0.021	<0.001	9.62	<0.002	<0.004	0.007	<0.004	0.004	3.86	4.69	0.001	5.62	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RSC	20000-19900	8.15	78	19	66	0.08	8.9	<0.06	0.15	<0.3	6.5	<0.0001	<0.003	0.03	<0.001	0.01	<0.001	5.33	<0.002	<0.004	0.009	<0.004	<0.003	1.57	2.8	<0.001	3.06	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RSC	19800-19600	9.26	117	40	82	0.09	8.5	<0.06	0.11	<0.3	9.4	<0.0001	<0.003	<0.02	0.002	0.27	<0.001	9.58	<0.002	<0.004	0.004	<0.004	<0.003	2.44	5.16	<0.001	2.06	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RAT	21100-20800	8.44	165	42	124	0.46	6.0	<0.06	0.98	<0.3	19	0.0002	<0.003	0.15	<0.001	0.006	<0.001	10.1	<0.002	0.01	0.13	<0.004	0.01	11.7	6.77	0.018	2.51	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RAT	20500-20400	6.91	35	1	64	0.12	1.1	<0.06	0.45	<0.3	6.6	<0.0001	<0.003	0.8	<0.001	<0.007	<0.001	1.32	<0.002	0.047	0.58	<0.004	0.14	2.86	2.27	0.069	0.42	<0.01	<0.002	<0.02	<0.005	<0.03	0.005
RAT	20300	8.6	34	5	36	0.16	1.0	<0.06	0.27	<0.3	5.5	<0.0001	<0.003	0.68	<0.001	0.24	<0.001	1.64	<0.002	<0.004	0.031	<0.004	0.19	1.48	2.76	0.008	0.38	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RAT	20200	8.82	48	26	42	0.05	1.1	<0.06	0.22	<0.3	4.1	<0.0001	<0.003	<0.02	<0.01	0.005	<0.001	2.5	<0.002	<0.004	<0.003	<0.004	<0.003	1.65	2.97	<0.001	0.37	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RAT	20100	6.88	17	2	14	0.05	0.9	<0.06	0.26	<0.3	2.6	<0.0001	<0.003	<0.02	<0.01	<0.002	<0.001	0.26	<0.002	0.043	0.13	<0.004	<0.003	1.25	0.48	0.046	0.54	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004
RAT	20000	6.38	12	2	26	0.03	0.5	<0.06	0.22	<0.03	1.8	<0.0001	<0.003	<0.02	<0.01	0.003	<0.001	0.19	<0.002	0.13	0.61	<0.004	<0.003	<0.8	0.35	0.025	0.18	<0.01	<0.002	<0.02	<0.005	<0.03	0.022
RAT	19900 - 19600	9.13	60	22	78	0.06	1.7	<0.06	0.22	<0.3	3.7	<0.0001	<0.003	<0.02	<0.01	0.06	0.001	4.98	<0.002	<0.004	<0.003	<0.004	<0.003	1.18	3.37	<0.001	0.66	<0.01	<0.002	<0.02	<0.005	<0.03	<0.004

Solution to Solid Ratio = 20 : 1

Analysis by EPA Method 1312

Table 5.4-3 Waste Rock SPLP Leach Test Results (2006)

	Unit	Drill Core Samples						Artisanal Material	
		SD-OX	RSC-OX	RAT-OX	SD-S	RSC-S	RSF-S	1	2
pH	s.u. (@ 25 °C)	6.5	6.4	6.2	6.4	6.5	6.5	5.8	5.6
Cond.	µS/cm (@ 25 °C)	596	448	337	595	571	565	126	99
Cl	mg/L	<5	<5	<5	<5	<5	<5	<5	<5
SO_4	mg/L	<5	<5	<5	11	<5	5	<5	<5
F	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ortho-PO_4	mg/L as P	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ag	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Al	mg/L	<0.001	0.125	<0.001	<0.001	<0.001	<0.001	0.022	<0.001
As	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ba	mg/L	0.027	0.251	0.813	0.123	0.746	0.349	0.016	0.010
Be	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	mg/L	0.120	2.92	0.569	1.31	1.09	1.11	2.86	2.17
Cr	mg/L	0.007	0.011	<0.001	<0.001	0.009	<0.001	<0.001	<0.001
Cu	mg/L	0.259	1.15	1.22	1.69	1.61	5.27	28.3	21.8
Fe	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hg	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mn	mg/L	0.689	1.56	0.766	0.534	0.527	0.415	0.157	0.057
Mo	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	0.005	<0.001	<0.001
Ni	mg/L	0.017	0.034	0.007	0.018	0.018	0.011	0.018	0.020
P	mg/L	<0.1	<0.1	0.158	<0.1	<0.1	<0.1	<0.1	0.135
Pb	mg/L	0.006	0.007	0.006	0.006	0.006	0.005	0.005	0.005
Sb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Se	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Th	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
U	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
V	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zn	mg/L	0.120	0.249	0.191	0.262	0.206	0.366	0.166	0.154
Au	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bi	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Br	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ca	mg/L	63.9	47.2	28.0	62.6	59.8	56.2	2.81	2.05
Ce	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cs	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Dy	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Er	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Eu	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ga	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 5.4-3 Waste Rock SPLP Leach Test Results (2006) (continued)

	Unit	Drill Core Samples						Artisanal Material	
		SD-OX	RSC-OX	RAT-OX	SD-S	RSC-S	RSF-S	1	2
Gd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ge	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hf	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ho	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
I	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ir	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
K	mg/L	2.26	1.38	1.97	1.93	1.05	1.80	1.22	1.37
La	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Li	mg/L	0.016	0.016	0.010	0.014	0.027	0.014	0.012	0.009
Lu	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mg	mg/L	41.6	29.4	23.9	40.6	39.4	36.9	2.25	1.67
Na	mg/L	1.82	2.17	1.82	1.48	2.41	2.13	1.27	1.31
Nb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Os	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pd	mg/L	0.001	0.002	0.001	<0.001	<0.001	0.001	0.001	0.001
Pr	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pt	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Rb	mg/L	0.003	0.003	0.005	0.002	0.002	0.003	0.001	0.001
Re	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Rh	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ru	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sc	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Si	mg/L	1.28	1.03	1.88	1.21	0.574	1.85	4.75	2.55
Sm	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sn	mg/L	<0.001	0.002	<0.001	<0.001	0.002	0.002	0.002	0.001
Sr	mg/L	0.094	0.154	0.064	0.145	0.154	0.074	0.016	0.012
Ta	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Te	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ti	mg/L	0.002	0.002	0.003	<0.001	<0.001	0.002	0.003	<0.001
Tl	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tm	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
W	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Y	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Yb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zr	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

SPLP leachate results for selected parameters are shown in Figures 5.4-2 to 5.4-13. The following parameters showed enhanced leaching at lower leachate pH: Ca, Co, Cu, Pb, Mg, Mn, Ni and Zn.

Cobalt and copper leachate concentrations versus pH are shown in Figures 5.4-4 and 5.4-5, respectively. Solubility curves for malachite [$Cu_2(CO_3)(OH)_2$], copper hydroxide [$Cu(OH)_3$], sphaerocobaltite [$CoCO_3$] and cobalt hydroxide are superimposed on these figures. Two solubility curves are shown for $CoCO_3$ based on thermodynamic data from different sources. The two curves for $CoCO_3$ illustrate the uncertainty in published thermodynamic data for this mineral.

At the lower range of pH values (below approximately pH 8.5), SPLP leachate concentrations for copper plot close to the malachite solubility curve. Cobalt concentrations plot close to the lower cobalt carbonate solubility curve. These figures indicate that leachate copper and cobalt concentrations may be solubility limited. SPLP cobalt and copper leachate concentrations versus solid phase concentrations are shown in Figures 5.4-14 and 5.4-15, respectively. The graphs show a positive correlation, in particular when deeper, more sulfidic samples and samples of artisanal waste are included in the comparison. The observed relationship between solid phase and leachate concentration would not be expected if leachate concentrations were mineral solubility limited.

At first glance, the correlation between copper/cobalt content and leachability appears to provide an attractive potential management tool (i.e., a threshold between “reactive” and “unreactive” waste rock based on a copper and/or cobalt content). However, when the leach test results are evaluated in terms of pH, it appears that leachability is controlled by leachate pH, with the low-pH leachates corresponding to those samples that have the higher total metals contents. Due to the small data set available for a detailed evaluation of these relationships (only one oxide waste sample for each of the three waste rock types), it is not possible to determine whether these observations represent a coincidence or are the result of geochemical characteristics that can be quantified and have a predictive value. The issue is further obfuscated by the fact that there appears to be a systematic bias between leachate results from Knight Piésold and Golder, with the latter consistently demonstrating a lower pH (and higher metal leachate concentrations), despite the fact that testing protocols appear to be similar, except for the degree of grain size reduction. Also, there is no correlation between leachate pH and paste pH (Figure 5.4-1), which appears to eliminate use of paste pH as a surrogate for leachability. Additional testing of waste rock samples is, therefore, required to generate a larger, more representative data set in support of developing waste rock management tools based on copper and/or cobalt content.

SPLP testing was conducted on a combined eight samples from each of the oxide waste classes (i.e., SD, RSC and RAT). Leachate results from each group of samples were compared to evaluate variability in metal leaching among material types. Figures 5.4-16 to 5.4-24 present summary statistics (minimum, maximum, median and average) for leachates from each type of oxide waste.

SPLP leachate for the RAT-OX samples reported lower average alkalinity and median pH values than the SD-OX and RSC-OX samples (Figure 5.4-16). The SD-OX samples appeared to have the greatest buffering capacity, as indicated by higher average alkalinity and median pH values. Trends in magnesium and calcium leachate concentrations also indicated greater buffering from calcite/dolomite in the SD-OX leachates than the RAT-OX leachates (Figure 5.4-17). RSC-OX average magnesium and calcium leachate concentrations were intermediate to those of the SD-OX and RAT-OX.

The SPLP leachate results indicate similar levels of metal leaching for the three oxide waste lithologies. The RAT-OX sample group reported slightly higher average aluminum, iron and copper leachate concentrations than the other sample groups (Figures 5.4-21, 5.4-23 and 5.4-22). Greater leaching of these metals is expected given the slightly lower median pH value for these samples.

5.4.1.2 NAG Test Leachate Results

NAG leach test results from the 2006 testing are shown in Table 5.4-4. Chemical analysis of NAG leachates is typically conducted to evaluate metal leaching for a reactive material (i.e., a sulfide waste) at terminal pH conditions.

As discussed previously, the NAG test results indicated no potential for acid generation. Leachate pH values for the three oxide, three sulfide and two artisanal material samples ranged from 6.4 to 7.8. The NAG test results therefore provide information on metal leaching under oxidized, circum-neutral pH conditions.

The solution to solid ratios for the SPLP and NAG leach tests are 20:1 and 100:1, respectively. NAG leachates are therefore potentially more “dilute” than SPLP leachates by a factor of five. NAG leachate concentrations indeed generally were lower than those measured in the SPLP tests; however, calculated loading rates fell within the range measured for the SPLP test. Cobalt concentrations in NAG leachates ranged from 0.2 to 25 milligrams per liter and were generally higher than those measured in SPLP leachates (between 0.12 and 2.92 milligrams per liter). In contrast, NAG leachate copper concentrations ranged from 0.13 to 0.66 milligrams per liter as compared to 0.26 to 28 milligrams per liter in SPLP leachates.

Table 5.4-4 Waste Rock NAG Leachate Results (2006)

	Unit	Drill Core Samples						Artisanal Material	
		SD-OX	RSC-OX	RAT-OX	SD-S	RSC-S	RSF-S	1	2
pH	s.u. (@ 25 °C)	6.4	7.8	7.0	7.7	7.6	7.6	7.7	7.0
Cl	mg/L	<5	<5	5	<5	6	<5	<5	<5
SO_4	mg/L	<5	9	<5	22	5	83	6	6
Ag	mg/L	<0.001	0.002	<0.001	0.004	0.001	<0.001	0.002	<0.001
Al	mg/L	3.31	0.151	5.44	0.444	0.027	<0.001	0.020	0.065
As	mg/L	0.002	0.003	0.001	0.005	0.003	0.030	0.007	0.014
B	mg/L	0.322	<0.1	0.247	<0.1	<0.1	<0.1	<0.1	0.140
Ba	mg/L	0.292	<0.001	0.157	<0.001	<0.001	<0.001	<0.001	0.209
Be	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	mg/L	0.241	1.631	0.549	0.938	0.732	4.39	25.1	19.2
Cr	mg/L	0.023	0.013	0.030	0.016	0.022	0.006	0.001	<0.001
Cu	mg/L	0.661	0.339	0.447	0.423	0.219	0.125	0.400	0.148
Fe	mg/L	1.450	<0.001	1.323	0.027	<0.001	<0.001	<0.001	<0.001
Hg	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mn	mg/L	0.598	0.647	0.957	0.161	0.056	0.058	0.009	0.004
Mo	mg/L	0.003	0.003	0.002	0.002	0.003	0.011	0.002	0.002
Ni	mg/L	0.023	0.022	0.038	0.024	0.019	0.025	0.053	0.050
P	mg/L	29.2	29.2	26.0	26.9	29.4	22.1	2.02	5.57
Pb	mg/L	0.004	0.006	0.004	0.006	0.005	0.005	0.007	0.005
Sb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Se	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.017	<0.01
Th	mg/L	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
U	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
V	mg/L	0.018	0.007	0.008	0.005	0.003	0.005	<0.001	0.006
Zn	mg/L	0.581	0.094	0.304	0.094	0.086	0.085	0.215	0.138
Au	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bi	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Br	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ca	mg/L	25.3	19.0	17.4	22.1	26.2	28.1	0.816	0.414
Ce	mg/L	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
Cs	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Dy	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Er	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Eu	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ga	mg/L	0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
Gd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ge	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hf	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ho	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
I	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ir	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
K	mg/L	4.21	1.05	4.36	2.10	1.01	1.17	1.53	2.61
La	mg/L	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	<0.001
Li	mg/L	0.031	0.018	0.038	0.014	0.025	0.012	0.020	0.019
Lu	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mg	mg/L	19.9	15.4	21.0	16.1	18.1	20.7	2.9	2.7
Na	mg/L	20.8	18.5	23.8	18.1	17.8	18.1	16.7	21.1

Table 5.4-4 Waste Rock NAG Leachate Results (2006) (continued)

	Unit	Drill Core Samples						Artisanal Material	
		SD-OX	RSC-OX	RAT-OX	SD-S	RSC-S	RSF-S	1	2
Nb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Os	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pd	mg/L	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001
Pr	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pt	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Rb	mg/L	0.008	0.003	0.009	0.003	0.002	0.002	0.002	0.004
Re	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Rh	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ru	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sc	mg/L	0.001	<0.001	0.003	<0.001	<0.001	<0.001	0.005	0.002
Si	mg/L	7.92	3.22	9.92	2.59	2.40	1.99	17.76	8.43
Sm	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sn	mg/L	0.002	0.001	0.002	0.002	0.002	<0.001	0.001	<0.001
Sr	mg/L	0.045	0.058	0.055	0.034	0.050	0.025	0.005	0.005
Ta	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Te	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ti	mg/L	0.097	0.079	0.131	0.071	0.075	0.060	0.006	0.018
Tl	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tm	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
W	mg/L	0.005	0.006	0.005	<0.001	<0.001	<0.001	<0.001	<0.001
Y	mg/L	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
Yb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zr	mg/L	0.002	<0.001	0.009	<0.001	<0.001	<0.001	<0.001	<0.001

In comparison to the SPLP leach test, NAG leachates also reported higher arsenic, chromium, molybdenum and nickel concentrations. Selenium was present in NAG leachate from one of the artisanal material samples. Selenium was below detectable limits (less than 0.01 milligrams per liter) in all other NAG leachates and all SPLP leachates.

5.4.1.3 Column Test Leachate Results

Column test leachate results for the three Golder oxide waste rock samples are shown in Tables 5.4-5 to 5.4-7. Results for selected parameters are shown in Figures 5.4-25 to 5.4-52. These figures also show SPLP and NAG testing results to facilitate comparison between the results from the various leach tests. Leachate pH and conductivity results are presented in Figures 5.4-25 and 5.4-26, respectively. Results for the remaining parameters presented in Figures 5.4-27 to 5.4-52 are arranged in alphabetical order by parameter name.

The solution to solid ratio for the oxide column testing was approximately 1:1, which represents a lower ratio than for the SPLP and NAG leach tests. For the SD-OX and RSC-OX columns, the residence time for one pore volume was typically one day. Due to the larger fraction of fines within the RAT-OX sample (Figure 5.1-1), flow through the column was slower, resulting in a longer residence time within the column (up to approximately 30 days). Leachate results for the RAT-OX column therefore represent leaching following longer interaction between the lixiviant and the solid sample. The RAT-OX column test was terminated at five pore volumes.

Leachate pH values for all three columns for the first pore volume were just below 8, ranging from 7.7 to 7.9. Leachate pH for all three columns increased over the first few pore volumes. Leachate pH for the SD-OX and RSC-OX columns stabilized at approximately 8 and 9, respectively (Figure 5.4-25). The final pH values were therefore higher than those reported for the SPLP and NAG tests. Leachate pH for the RAT-OX column was relatively stable at 8.3 at 5 pore volumes.

Leachate conductivity was initially high for all samples, ranging from 440 to 520 micro Siemens per centimeter in leachates representing the first pore volume. A rapid decline in conductivity was observed in all column leachates between pore volumes 1 and 3. Leachate conductivity for the SD-OX and RSC-OX columns stabilized at approximately 35 and 50-55 micro Siemens per centimeter, respectively (Figure 5.4-26). The observed rapid decline in conductivity is often encountered in column leach tests and represents the initial flush of readily-soluble components and possibly mobilization of the finest fraction of the sample. At five pore volumes, RAT-OX leachate conductivity had not yet stabilized and showed a decreasing trend. Pore volume five RAT-OX leachate conductivity was higher than that observed for the other two samples after five pore volumes of leaching.

Table 5.4-5 Column Leach Test Results – SD-OX

Parameter	Units	SD-OX										
		Pore Volume										
		1	2	3	4	5	6	7	8	9	10	11
pH	s.u.	7.7	7.6	7.9	8.2	8.1	8.3	8.0	8.0	8.2	8.0	8.2
electrical conductivity	µS/cm (@ 25 °C)	490	137	92	75	62	57	37	36	39	37	34
total alkalinity	mg/L as $CaCO_3$	104	44	36	32	28	24	20	20	20	20	22
Cl	mg/L	36	5	<5	<5	<5	<5	<5	<5	<5	<5	<5
SO_4	mg/L	51	11	<5	<5	<5	<5	5	<5	6	<5	<5
F	mg/L	1.1	0.4	0.3	0.2	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
PO_4	mg/L as P	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ag	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Al	mg/L	0.255	0.021	0.141	0.021	0.361	0.046	0.021	0.017	0.019	0.016	0.014
As	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Au	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ba	mg/L	0.007	<0.001	0.070	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.026	<0.001
Be	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bi	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Br	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ca	mg/L	25.2	9.68	8.27	6.15	4.51	4.62	3.18	3.06	3.14	2.83	1.14
Cd	mg/L	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ce	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	mg/L	0.009	0.004	0.005	0.002	0.003	0.003	0.002	0.003	0.003	0.003	0.002
Cr	mg/L	<0.001	<0.001	0.028	<0.001	0.006	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
Cs	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cu	mg/L	0.175	0.035	0.033	0.017	0.015	0.520	0.010	0.013	0.008	0.012	0.009
Dy	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 5.4-5 Column Leach Test Results – SD-OX (continued)

Parameter	Units	SD-OX										
		Pore Volume										
		1	2	3	4	5	6	7	8	9	10	11
Er	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Eu	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Fe	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ga	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Gd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ge	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hf	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hg	mg/L	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ho	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
I	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ir	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
K	mg/L	19.7	5.06	2.49	1.92	2.64	1.45	0.792	0.809	0.751	0.766	0.698
La	mg/L	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Li	mg/L	0.097	0.016	0.012	0.010	0.011	0.008	0.006	0.007	0.006	0.006	0.005
Lu	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mg	mg/L	27.6	7.46	5.47	3.52	2.86	2.75	1.83	1.81	1.77	3.03	1.66
Mn	mg/L	0.010	0.003	0.010	<0.001	0.002	<0.001	0.001	0.002	0.003	0.002	0.002
Mo	mg/L	0.026	0.011	0.006	0.005	0.003	0.002	<0.001	<0.001	0.001	0.003	0.002
Na	mg/L	13.3	1.89	1.03	0.458	0.356	0.210	0.096	0.125	0.087	0.075	0.069
Nb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ni	mg/L	0.007	0.004	0.018	<0.001	0.002	0.004	<0.001	0.008	0.004	0.003	0.003
Os	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
P	mg/L	<0.1	<0.1	0.261	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table 5.4-5 Column Leach Test Results – SD-OX (continued)

Parameter	Units	SD-OX										
		Pore Volume										
		1	2	3	4	5	6	7	8	9	10	11
Pb	mg/L	0.054	0.001	0.042	0.003	0.002	0.016	0.002	0.002	<0.001	0.002	0.002
Pd	mg/L	<0.001	0.001	0.002	<0.001	<0.001	0.015	<0.001	<0.001	<0.001	<0.001	<0.001
Pr	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pt	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Rb	mg/L	0.018	0.005	0.003	0.002	0.002	0.002	<0.001	<0.001	<0.001	0.001	0.001
Re	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Rh	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ru	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sc	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Se	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Si	mg/L	1.75	1.19	1.56	1.42	1.25	1.16	0.691	0.673	1.52	1.85	1.160
Sm	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sn	mg/L	<0.001	<0.001	0.002	0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
Sr	mg/L	0.146	0.059	0.048	0.036	0.029	0.026	0.015	0.014	0.014	0.015	0.013
Ta	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Te	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Th	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ti	mg/L	<0.001	<0.001	0.006	<0.001	<0.001	<0.001	<0.001	0.001	0.002	<0.001	<0.001
Tl	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tm	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
U	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
V	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 5.4-5 Column Leach Test Results – SD-OX (continued)

Parameter	Units	SD-OX										
		Pore Volume										
		1	2	3	4	5	6	7	8	9	10	11
W	mg/L	0.011	0.005	0.009	0.004	0.004	0.003	<0.001	<0.001	0.001	0.003	0.001
Y	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Yb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zn	mg/L	0.020	0.044	5.31	<0.001	0.774	0.040	<0.001	0.504	<0.001	<0.001	<0.001
Zr	mg/L	<0.001	<0.001	0.012	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 5.4-6 Column Leach Test Results – RSC-OX

Parameter	Units	RSC-OX										
		Pore Volume										
		1	2	3	4	5	6	7	8	9	10	11
pH	s.u.	7.9	8.6	9.0	8.8	8.9	8.8	8.7	8.8	8.9	8.7	8.8
electrical conductivity	µS/cm (@ 25 °C)	440	134	85	76	72	68	65	60	57	54	51
total alkalinity	mg/L as $CaCO_3$	76	42	32	32	32	32	32	32	30	30	30
Cl	mg/L	54	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
SO_4	mg/L	55	15	7	<5	<5	<5	<5	<5	<5	<5	<5
F	mg/L	0.3	0.2	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
PO_4	mg/L as P	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ag	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Al	mg/L	<0.001	<0.001	0.038	0.046	<0.001	0.029	0.016	0.024	0.005	0.008	0.012
As	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Au	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ba	mg/L	0.031	0.015	0.014	0.020	0.023	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Be	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bi	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Br	mg/L	0.165	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ca	mg/L	20.7	11.0	7.91	7.61	7.35	3.05	1.75	1.44	1.56	1.07	0.989
Cd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ce	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Co	mg/L	0.024	0.008	0.006	0.004	0.005	0.003	0.002	0.002	0.001	0.001	0.001
Cr	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cs	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cu	mg/L	0.071	0.051	0.018	0.016	0.011	0.009	0.007	0.006	0.003	0.003	0.002
Dy	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Er	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Eu	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 5.4-6 Column Leach Test Results – RSC-OX (continued)

Parameter	Units	RSC-OX										
		Pore Volume										
		1	2	3	4	5	6	7	8	9	10	11
Fe	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ga	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Gd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ge	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hf	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Hg	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ho	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
I	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ir	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
K	mg/L	14.6	3.05	1.43	1.09	0.731	0.601	0.487	0.326	0.294	0.236	0.184
La	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Li	mg/L	0.066	0.019	0.011	0.015	0.006	0.004	0.003	0.003	0.002	0.002	0.002
Lu	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mg	mg/L	18.1	6.51	4.29	3.60	3.35	1.91	1.25	0.968	0.743	0.607	0.473
Mn	mg/L	0.013	0.005	0.003	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mo	mg/L	0.007	0.008	0.005	0.004	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Na	mg/L	16.7	1.55	0.371	0.275	0.100	0.058	0.046	0.042	0.034	0.026	0.020
Nb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ni	mg/L	0.006	0.006	0.007	0.011	0.007	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Os	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
P	mg/L	<0.1	<0.1	0.126	0.159	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pb	mg/L	<0.001	0.004	0.002	0.002	0.001	0.002	0.001	0.001	<0.001	<0.001	<0.001
Pd	mg/L	<0.001	0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pr	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pt	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 5.4-6 Column Leach Test Results – RSC-OX (continued)

Parameter	Units	RSC-OX										
		Pore Volume										
		1	2	3	4	5	6	7	8	9	10	11
Rb	mg/L	0.017	0.005	0.002	0.002	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Re	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Rh	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ru	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sc	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Se	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Si	mg/L	2.35	1.99	1.56	1.71	1.41	0.457	0.286	0.172	0.209	0.144	0.169
Sm	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sn	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001	<0.001	<0.001	<0.001
Sr	mg/L	0.378	0.219	0.169	0.157	0.157	0.015	0.012	0.010	0.008	0.003	0.003
Ta	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Te	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Th	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Ti	mg/L	<0.001	0.011	<0.001	0.006	<0.001	0.009	0.004	0.002	0.005	0.004	0.005
Tl	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tm	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
U	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
V	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
W	mg/L	0.007	0.005	0.003	0.004	0.003	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Y	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Yb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zn	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zr	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 5.4-7 Column Leach Test Results – RAT-OX

Parameter	Units	RAT-OX				
		Pore Volume				
		1	2	3	4	5
pH	s.u.	7.9	8.2	8.3	8.2	8.3
electrical conductivity	µS/cm (@ 25 °C)	520	190	155	116	104
total alkalinity	mg/L as $CaCO_3$	136	80	68	64	62
Cl	mg/L	16	<5	<5	<5	<5
SO_4	mg/L	62	11	5	5	<5
F	mg/L	0.7	0.7	0.3	0.3	0.2
PO_4	mg/L as P	<0.2	<0.2	<0.2	<0.2	<0.2
Ag	mg/L	<0.001	0.001	<0.001	<0.001	<0.001
Al	mg/L	<0.001	<0.001	0.019	<0.001	0.001
As	mg/L	<0.001	0.005	0.001	<0.001	<0.001
Au	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
B	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1
Ba	mg/L	0.077	0.014	0.144	0.076	0.049
Be	mg/L	<0.001	<0.001	0.006	0.001	<0.001
Bi	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Br	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1
Ca	mg/L	16.5	12.8	7.0	4.4	2.8
Cd	mg/L	<0.001	0.002	<0.001	<0.001	<0.001
Ce	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Co	mg/L	0.184	0.027	<0.001	<0.001	0.001
Cr	mg/L	<0.001	0.016	0.001	0.002	0.002
Cs	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Cu	mg/L	0.563	0.094	0.022	0.016	0.012
Dy	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Er	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Eu	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Fe	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ga	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Gd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ge	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Hf	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Hg	mg/L	<0.001	<0.001	0.004	0.001	<0.001
Ho	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
I	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1
Ir	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
K	mg/L	18.7	14.3	6.2	2.4	1.0
La	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Li	mg/L	0.067	0.023	0.007	0.004	0.003
Lu	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001

Table 5.4-7 Column Leach Test Results – RAT-OX (continued)

Parameter	Units	RAT-OX				
		Pore Volume				
		1	2	3	4	5
Mg	mg/L	33.1	14.5	8.7	6.7	5.6
Mn	mg/L	0.246	0.084	0.018	0.009	0.004
Mo	mg/L	0.020	0.018	0.008	0.006	0.001
Na	mg/L	17.1	5.5	0.5	0.3	0.2
Nb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Nd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ni	mg/L	0.014	0.022	0.003	0.001	0.001
Os	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
P	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1
Pb	mg/L	0.002	0.003	0.004	0.003	<0.001
Pd	mg/L	0.001	0.002	0.001	<0.001	<0.001
Pr	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Pt	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Rb	mg/L	0.023	0.013	0.009	0.006	0.003
Re	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Rh	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ru	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Sb	mg/L	<0.001	<0.001	0.002	<0.001	<0.001
Sc	mg/L	<0.001	0.002	0.001	<0.001	0.001
Se	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Si	mg/L	4.30	4.39	2.83	2.28	1.91
Sm	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Sn	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Sr	mg/L	0.107	0.075	0.057	0.039	0.026
Ta	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Tb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Te	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Th	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Ti	mg/L	0.001	0.003	0.003	0.002	0.001
Tl	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Tm	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
U	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
V	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
W	mg/L	0.006	0.006	0.011	0.004	0.001
Y	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Yb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Zn	mg/L	<0.001	<0.001	<0.001	<0.001	0.001
Zr	mg/L	<0.001	0.001	0.002	<0.001	<0.001

Consistent with the observed declines in conductivity, leachate major ion concentrations (i.e., alkalinity, Ca, Cl, Mg, K, Na and SO_4) all decreased between pore volumes 1 and 2 (Figures 5.4-27, 5.4-33, 5.4-34, 5.4-40, 5.4-45, 5.4-48 and 5.4-49, respectively). Major ion concentrations in SD-OX and RSC-OX leachates were stable at the termination of testing. Leachate alkalinity for the SD-OX and RSC-OX columns stabilized at approximately 20 and 30 milligrams per liter, respectively (Figure 5.4-27). Sulfate and chloride leachate concentrations stabilized at below detectable limits (less than five milligrams per liter) for both SD-OX and RSC-OX samples (Figures 5.4-49 and 5.4-34, respectively).

Cobalt and copper leachate concentrations generally declined over the testing period (Figures 5.4-36 and 5.4-37, respectively). Leachate concentrations at the termination of testing were on the order of micrograms per liter to tens of micrograms per liter. SD-OX copper leachate concentrations were stable at 11 pore volumes, whereas RSC-OX leachate concentrations were still trending downward. RAT-OX copper leachate concentrations were also trending downward at five pore volumes.

For some metals (i.e., Al, Cr, Pb and Zn), greater metal leaching was observed for the SD-OX sample than the RSC-OX sample (Figures 5.4-28, 5.4-35, 5.4-39 and 5.4-50, respectively). For these parameters, leachate concentration trends were more erratic than those observed for the major ions. Elemental analysis indicated higher Cr, Pb and Zn contents for the SD-OX sample than the RSC-OX sample. The observed metal leaching behavior may be attributable to differences in sample composition; however, the observed variability may also be due to differences in reactive surface area. As shown in Figure 5.1-1, the SD-OX sample has a higher surface area than the RSC-OX sample. In addition, differences in metals mobility may be the result of differences in leachate pH.

Manganese, molybdenum and nickel leaching were observed for all three samples (Figures 5.4-41, 5.4-42 and 5.4-43, respectively). Leachate concentrations generally decreased over the period of testing to microgram per liter levels.

Arsenic, antimony, boron, iron and selenium were consistently below detectable limits in SD-OX and RSC-OX leachates over the period of testing. These parameters were also consistently below detectable limits in RAT-OX leachates, with the exception of detections of arsenic (Figure 5.4-30) and antimony (Figure 5.4-46) in leachates representing pore volumes 2 and 3. NAG and SPLP test results also showed low metal leaching potential for arsenic, antimony and selenium. NAG testing indicated a potential for iron and boron leaching from the SD-OX and RAT-OX samples.

5.4.1.3 Summary of Waste Rock Metal Leaching

Three types of leach test were preformed to assess metal leaching from waste rock: SPLP, NAG and column testing. The waste rock metal leaching evaluation focused on the oxide waste. Limited data are available to assess metal leaching from sulfide waste rock.

Leachate pH values for all tests ranged from circum-neutral to alkaline (pH 6.2 to 9.8). Test results therefore provide data on metal leaching under this range of pH conditions. Leachate test results at the higher end of the pH range may reflect equilibrium with dolomite, which has an abrasion pH of 9 to 10 (Price 1997).

Metal leaching results for the three oxide waste rock types were generally similar. Copper and cobalt leaching was observed for all waste rock types. For both constituents, metal leaching was observed to increase as pH decreased (Figures 5.4-4, 5.4-5, 5.4-51 and 5.4-52). The Golder SPLP tests indicated a positive correlation between solid phase cobalt and copper concentrations and leachate concentrations. Leach test results plotted versus pH suggest that copper and cobalt leachate concentrations may be limited by malachite and cobalt carbonate solubility, respectively.

In addition to cobalt and copper, SPLP leach test results indicated enhanced leaching for the following parameters at lower pH conditions: Ca, Pb, Mg, Mn, Ni and Zn. All leach tests further demonstrated a low leaching potential for leaching of arsenic (up to microgram per liter levels), antimony (all less than 0.001 milligrams per liter) and selenium (all less than 0.01 milligrams per liter) from the oxide waste rock samples. SPLP test results for the sulfide waste samples also indicated low selenium and antimony mobility. SPLP test results for the sulfide and artisanal material samples indicated low arsenic mobility. The NAG test results indicated enhanced mobility of arsenic for the sulfide and artisanal samples relative to the oxide waste.

Column leach testing of three oxide waste rock samples indicated a potential for release of aluminum, chromium, lead, manganese, molybdenum, nickel and zinc. Concentrations generally decreased over time. Leachate pH values stabilized at alkaline values (between 8 and 9). A decrease in metal leaching over time may in part be attributable to an increase in pH.

Table 5.4-8 Site Ponded Water Quality Results

Parameter	Units	TFM GAA01	TFM GAA02	TFM GAA03
Field Analysis				
pH	s.u.	8.32	7.14	7.64
Temperature	°C	20.4	19.9	20.6
Electrical Conductivity	µS/cm	26	8	16
Dissolved Oxygen	mg/L	5.53	4.35	3.68
Dissolved Oxygen	% Saturation	71.7	55.3	67.4
ORP	mV	346	344	386
Laboratory Analysis				
pH	s.u.	5.9	6.2	6.0
Conductivity	µS/cm	26.4	9.47	22.2
Total Dissolved Solids	mg/L	32	22	30
Total Hardness	mg/L as $CaCO_3$	8.5	11	15
Total Alkalinity	mg/L as $CaCO_3$	6	8	10
Ca	mg/L	0.1	<0.1	0.4
Mg	mg/L	2.0	2.6	3.5
Na	mg/L	1.6	4	4.2
K	mg/L	1.6	0.1	1.5
Cl	mg/L	3.7	3.7	4.7
SO_4	mg/L	1.6	1.6	1.9
F	mg/L	0.2	<0.1	<0.1
Nitrate	mg/L-N	1.2	0.8	1.5
Nitrite	mg/L-N	<0.1	<0.1	<0.1
Total Suspended Solids	mg/L	648	384	314
Total Solids	mg/L	680	406	344
Biochemical Oxygen Demand	mg/L	0.3	0.8	0.3
Chemical Oxygen Demand	mg/L	13	53	9
Color	Hazen Units	<5	5	10
Total Phosphate, PO_4	mg/L	0.4	<0.1	<0.1
Ag	mg/L	<0.004	<0.004	<0.004
Al	mg/L	2.8	3.3	6.5
As	mg/L	<0.02	<0.02	<0.02
B	mg/L	<0.006	<0.006	0.02
Ba	mg/L	0.02	0.10	0.01
Be	mg/L	<0.002	<0.002	<0.002
Cd	mg/L	<0.001	<0.001	<0.001
Co	mg/L	0.96	0.15	0.46
Cr	mg/L	0.003	0.004	0.007
Cu	mg/L	1.4	0.9	0.56
Fe	mg/L	0.55	0.86	2.1

Table 5.4-8 Site Ponded Water Quality Results (continued)

Parameter	Units	TFM GAA01	TFM GAA02	TFM GAA03
Hg	mg/L	<0.001	<0.001	<0.001
Mn	mg/L	<0.001	<0.001	0.008
Mo	mg/L	0.001	0.002	0.001
Ni	mg/L	<0.003	0.004	<0.003
Pb	mg/L	<0.01	<0.01	<0.01
Sb	mg/L	<0.01	<0.01	<0.01
Se	mg/L	<0.03	<0.03	<0.03
Si	mg/L	6.3	6.2	10.8
Sn	mg/L	<0.02	<0.02	<0.02
Sr	mg/L	<0.001	<0.001	<0.001
Th	mg/L	<0.002	<0.002	<0.002
U	mg/L	<0.004	<0.004	<0.004
V	mg/L	0.01	0.04	0.02
Zn	mg/L	<0.005	0.02	<0.005

Water quality results for three water samples collected from pools of standing water in contact with artisanal waste are shown in Table 5.4-8. These data are presented for comparison of metal leaching under field and laboratory conditions. Only dissolved phase metal concentrations are presented. It should be noted that samples from ponded water do not always accurately reflect the quality of water resulting from contact with mining materials. In particular, evaporation may lead to elevated concentrations that would not be observed in discharges (e.g., runoff, seepage) generally originating from mine facilities. However, since the pond water samples were collected after significant rainfall events, they are considered a useful approximation of runoff water quality.

A significant decline in pH was observed for the ponded water samples between field and laboratory measurement. The reason for this decline is not known. Decreases in pH between field and laboratory measurements generally are attributed to an increase in the carbon dioxide content after collection of the water sample. However, this usually applies to groundwater samples that have been isolated from atmospheric conditions, as opposed to surface water samples which are in equilibrium with the atmosphere. The laboratory measured values were similar to the SPLP leachate measurements for the artisanal material samples.

Dissolved iron and aluminum were present in all ponded water samples ranging from 0.5 to 6.5 milligrams per liter. At near-neutral pH conditions (as indicated by the field measurements) in an oxidized environment, these concentrations are higher than expected. The field data indicate a potential for iron leaching, whereas laboratory testing indicated low iron mobility.

Copper and cobalt occur in the ponded water samples at 100s of micrograms per liter to milligram per liter concentrations. These data confirm mobilization of copper and cobalt as observed in the laboratory leach tests.

Chromium, manganese, molybdenum, nickel and zinc were all detected in one or more ponded water samples at microgram per liter levels. Laboratory testing also indicated a potential for leaching of these metals. The detection limits for arsenic and lead in site waters were too high to assess metal leaching at microgram per liter levels.

Site water vanadium concentrations suggest greater mobility than observed in the SPLP and column tests.

5.4.2 Tailings and Ore

5.4.2.1 SPLP Leach Test Results

SPLP leach test results for ore and tailings are shown in Table 5.4-9.

SPLP leach testing of the bench upper tailings with pH 6.2 and 4.2 lixiviant yielded similar results. Final leachate pH values for both tests were near neutral (approximately 7.5). Cobalt and copper leachate concentrations were low, and ranged from microgram per liter concentrations up to 11 micrograms per liter.

SPLP leachate results for the bulk upper tailings sample were generally similar to those for the bench upper tailings. Leachate pH (8.6) was approximately 1 pH unit higher for the bulk sample leachate in comparison to the bench sample leachates. The bulk sample leachate calcium concentration was also higher than the bench sample. Differences in leachate pH and calcium concentrations likely reflect differences in the degree of neutralization of the bench and bulk tailings samples. The bulk tailings sample was neutralized to a pH of approximately 9, whereas the bench sample was neutralized to a pH of approximately 7. Cobalt and copper leachate concentrations for the bulk sample (0.010 and 0.044 milligrams per liter, respectively) were higher than the leachate concentrations for the bench sample. The bulk sample also showed greater iron leaching than the bench sample. Iron was measured at 0.1 milligrams per liter in bulk sample leachate and was below detectable limits (less than 0.01 milligrams per liter) in the bench sample leachates.

Table 5.4-9 Ore and Tailings SPLP Leach Test Results

Parameter	Units	Ore (Bulk Upper)				Tailings (Bench Upper)				Tailings (Bulk Upper)		Tailings (Combined)		Tailings (FAM Solids)	
SPLP pH	s.u.	6.2		4.2		6.2		4.2		4.2		4.2		4.2	
pH	s.u.	6.97		6.55		7.54		7.58		8.56		6.40		6.18	
conductivity	µS/cm	14.6		13		59.7		96		101		816		2,232	
alkalinity	mg/L as $CaCO_3$	-		-		-		-		29.8		9.3		8.8	
sulfate	mg/L	-		-		-		-		20		442		1,490	
ortho-phosphate	mg/L	-		-		-		-		0.357		0.063		0.053	
chloride	mg/L	-		-		-		-		<0.5		2.9		<0.5	
fluoride	mg/L	-		-		-		-		0.09		0.04		0.04	
hardness	mg/L as $CaCO_3$	0.2		2.2		26.3		34.7		46.7		472		1530	
Ag	mg/L	< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005	
Al	mg/L	0.013		< 0.001		0.038		0.02		0.17		< 0.001		0.009	J+
As	mg/L	0.0007		0.0002		0.013		0.015		0.013		0.0033		0.0011	
B	mg/L	0.02		0.02		< 0.01		< 0.01		< 0.01		< 0.01		< 0.01	
Ba	mg/L	< 0.0002		0.0006	J+	0.015		0.029		0.0058	J+	0.036		0.0012	J+
Be	mg/L	< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002	
Bi	mg/L	< 0.0002		< 0.0002		0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002	
Ca	mg/L	0.04	J+	0.5		10.3		13.6		18.3		185		573	
Cd	mg/L	< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004	
Co	mg/L	0.0064		0.154		0.0032		0.0016		0.0097		0.0028		2.02	
Cr	mg/L	0.0003		< 0.0002		0.0003		0.0003		0.0005		0.0005		0.034	
Cu	mg/L	0.061		0.173		0.011		0.0078	J+	0.044		0.0053	J+	0.075	
Fe	mg/L	< 0.01		0.01		< 0.01		< 0.01		0.1		< 0.01		0.01	
Hg	mg/L	-		< 0.00002		-		< 0.00002		< 0.00002		< 0.00002		< 0.00002	
K	mg/L	2.55		2.3		0.1		0.33	J+	0.29	J+	1.08		0.78	
Li	mg/L	0.0078		0.0056		0.0005		0.0009		0.0017		0.0054		0.0039	

Table 5.4-9 Ore and Tailings SPLP Leach Test Results (continued)

Parameter	Units	Ore (Bulk Upper)				Tailings (Bench Upper)				Tailings (Bulk Upper)		Tailings (Combined)		Tailings (FAM Solids)	
Mg	mg/L	0.03		0.24		0.11		0.18		0.23		2.21		23	
Mn	mg/L	0.0003		0.0033	J+	0.0015		0.0016	J+	0.0004	J+	0.0003	J+	0.0098	J+
Mo	mg/L	0.0007		0.0002		0.0067		0.01		0.0062		0.011		0.0032	
Na	mg/L	1.59		0.21	J+	0.34	J+	0.54		0.41		2.03		0.65	
Ni	mg/L	< 0.0002		0.0006		0.0003		< 0.0002		0.0002		< 0.0002		0.005	
P	mg/L	< 0.03		< 0.03		0.17		0.16		0.31		0.06		0.05	
Pb	mg/L	< 0.0002		< 0.0002		< 0.0002		< 0.0002		0.0002	J+	< 0.0002		< 0.0002	
Rb	mg/L	0.0011		0.0018		< 0.0002		0.0003		0.0003		0.001		0.0007	
Sb	mg/L	0.0003		< 0.0002		0.005		0.0053		0.0042		0.0009		< 0.0002	
Se	mg/L	< 0.0002		< 0.0002		< 0.0002		0.0004		< 0.0002		0.0024		0.003	
Si	mg/L	2.5		2.07		22.7		21.2		40.9		4.56		2.56	
Sn	mg/L	0.0003		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		0.0003	
Sr	mg/L	< 0.0002		0.0013		0.023		0.033		0.031		0.282		1.9	
Te	mg/L	< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002	
Th	mg/L	< 0.0001		< 0.0001		0.0001		< 0.0001		0.0001		< 0.0001		< 0.0001	
Ti	mg/L	0.0004		< 0.0002		0.0014		0.001		0.0028		< 0.0002		< 0.0002	
Tl	mg/L	< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		0.00003		0.00004	
U	mg/L	< 0.0001		< 0.0001		< 0.0001		< 0.0001		0.0001		< 0.0001		0.0001	
V	mg/L	0.0002		< 0.0002		0.0004		0.0004		0.0032		0.0004		0.0063	
W	mg/L	< 0.0002		< 0.0002		0.0023		0.0038		< 0.0002		< 0.0002		< 0.0002	
Zn	mg/L	< 0.001		0.005	J+	0.002	J+	0.002	J+	0.002	J+	< 0.001		< 0.001	
Zr	mg/L	< 0.002		< 0.002		< 0.002		< 0.002		0.003		< 0.002		< 0.002	

Solution to Solid Ratio = 20 : 1

Sample Mass = 100 g

Extract Volume = 2000 mL

J+ - Result qualified as biased high due to detection of analyte in blank. Analyte concentration in sample is less than 10 times the concentration reported in the blank.

Leachate pH values for the combined tailings and FAM solids leachates were lower than those measured for the other tailings (6.4 and 6.2, respectively). In comparison to the bench upper and bulk upper SPLP leachates, the combined tailings and FAM solids reported higher sulfate, calcium and magnesium concentrations. Selenium was detected at part per billion concentrations in both the combined tailings and FAM SPLP leachates. In the other tailings leachates, selenium concentrations were below detectable limits or less than a part per billion. In comparison to all tailings samples, the FAM solids SPLP leachate reported higher cobalt, chromium, copper and nickel concentrations.

Leachate pH values for the two bulk ore sample tests were similar at 7.0 and 6.6. The bulk upper ore sample yielded higher cobalt and copper leachate concentrations than the tailings samples (excluding the FAM solids sample). Cobalt and copper leachate concentrations were highest for the bulk ore sample leached with pH 4.2 lixiviant at 0.15 and 0.17 milligrams per liter, respectively. This result is consistent with the waste rock leach test results which also showed greater cobalt and copper mobility under lower pH conditions.

The bench and bulk tailings sample results both indicated a potential for arsenic leaching. Leachate concentrations were consistent for the three tailings leach tests, ranging from 0.013 to 0.015 milligrams per liter. Arsenic concentrations in the combined tailings and FAM solids leachates were lower at a few parts per billion. The ore sample leachates reported even lower arsenic concentrations (less than 1 microgram per liter).

The following metals were present in leachates from tailings (excluding the FAM solids) and ore at microgram per liter concentrations or below: Cr, Li, Mn, Mo, Ni, Rb, Sb, Ti, V and Zn. SPLP leachates results therefore indicate a potential for some mobilization of these constituents at near neutral to alkaline pH values.

SPLP results for the tailings indicated a potential for phosphorus leaching. Phosphorus was below detectable limits in the bulk ore leachates (<0.03 milligrams per liter). Leachate results reported a range of aluminum concentrations, ranging from below detectable limits (less than 0.001 milligrams per liter) to 0.2 milligrams per liter. Leachate aluminum concentrations were generally higher for the tailings samples than the ore sample.

The following constituents were at or below detectable limits in all leachates from ore and tailings: Ag, Be, Bi, Cd, Hg, Pb, Te and Th. SPLP leach test results indicated a low potential for the leaching of these constituents at near neutral to alkaline pH conditions. Thallium and uranium were also generally very low or below detectable limits (less than 0.1 micrograms per liter).

5.4.2.2 NAG Test Leachate Results

NAG test leachate results for ore and tailings are shown in Table 5.4-10.

NAG leachate pH values for the bulk ore and bench tailings sample were 7.9 and 7.5, respectively. For the ore sample, the NAG pH value was higher than that of the ore SPLP leachates. The bench tailings NAG pH value was within the range measured in tailings SPLP leachates. NAG leachate results provide data on metal leaching under oxidizing conditions at near neutral pH.

Table 5.4-10 Ore and Tailings NAG Leach Test Results

Parameter	Units	Tailings (Bench Upper)	Ore (Bulk Upper)
final NAG pH	s.u.	7.53	7.88
hardness	mg/L as $CaCO_3$	39.8	20.6
Ag	mg/L	0.00058	< 0.00005
Al	mg/L	0.009	0.024
As	mg/L	0.018	0.0029
B	mg/L	0.01	0.03
Ba	mg/L	0.0027	0.001
Be	mg/L	< 0.0002	< 0.0002
Bi	mg/L	< 0.0002	< 0.0002
Ca	mg/L	11.5	2.9
Cd	mg/L	< 0.00004	< 0.00004
Co	mg/L	0.0083	0.017
Cr	mg/L	0.027	0.025
Cu	mg/L	0.015	0.081
Fe	mg/L	< 0.01	< 0.01
Hg	mg/L	< 0.00002	< 0.00002
K	mg/L	3.97	6.58
Li	mg/L	0.0092	0.03
Mg	mg/L	2.66	3.24
Mn	mg/L	0.0091	0.0006
Mo	mg/L	0.014	0.0031
Na	mg/L	33.3	29.7
Ni	mg/L	0.0004	< 0.0002
P	mg/L	20.8	2.46
Pb	mg/L	< 0.0002	< 0.0002
Rb	mg/L	0.0054	0.015
Sb	mg/L	0.0036	0.0007
Se	mg/L	0.0007	0.0056
Si	mg/L	8.95	8.69
Sn	mg/L	0.0006	0.0007
Sr	mg/L	0.032	0.011
Te	mg/L	< 0.0002	< 0.0002
Th	mg/L	< 0.0001	< 0.0001
Ti	mg/L	0.0093	0.0012
Tl	mg/L	< 0.00002	< 0.00002
U	mg/L	< 0.0001	< 0.0001
V	mg/L	0.0092	0.0076
W	mg/L	0.019	< 0.0002
Zn	mg/L	0.002	0.002
Zr	mg/L	< 0.002	< 0.002

Solution to Solid Ratio = 100 : 1
Sample Mass = 2.5 g
Leachate Volume = 250 mL
s.u. = standard unit

Consistent with SPLP test results, cobalt and copper NAG test leachate concentrations were higher for the ore than the tailing sample. Copper NAG leachate concentrations for the ore and tailing were 0.081 and 0.015 milligrams per liter, respectively, falling within the ranges measured in SPLP leachates. Cobalt NAG leachate concentrations for the ore and tailing were 0.017 and 0.0083 milligrams per liter, respectively, also falling within the ranges measured in SPLP leachates.

Consistent with the SPLP leach test results, NAG test results indicated greater arsenic leaching from the tailing sample than the ore sample. NAG arsenic leachate concentrations for the bench tailing sample were similar to the SPLP leach test results. Although the NAG test arsenic leachate concentration for the ore sample was low (0.003 milligrams per liter); it was higher than that measured in SPLP leachates.

The NAG leach test results indicated a potential for phosphorus leaching from both the tailing and ore samples. Consistent with the SPLP test results, the tailings sample yielded higher phosphorus leachate concentrations. The NAG test leachate concentrations were, however, much higher than those observed in the SPLP leach tests (Figure 5.4-44).

Chromium NAG leachate concentrations for both the tailing and ore sample were approximately 0.03 milligrams per liter. These concentrations are orders of magnitude higher than the concentrations measured in the SPLP leachates, which ranged from below detectable limits (less than 0.0002 milligrams per liter) to 0.0005 milligrams per liter (Figure 5.4-35). NAG testing also yielded slightly higher Mo and Se leachate concentrations than SPLP testing (despite a higher solution to solid ratio). Chromium, molybdenum and selenium occur mainly as oxyanions in oxidizing environments. Their enhanced mobility in the NAG tests may result from the oxidizing conditions of test.

Consistent with SPLP leach test results, the following metals were present in NAG ore and tailing leachates at microgram per liter concentrations and below: Mn, Sb, Ti, V and Zn. NAG leachates results indicate a potential for some mobilization of these constituents at near neutral to alkaline pH values.

Consistent with SPLP leach test results, the following constituents were at or below detectable limits in NAG test ore and tailing sample leachates: Be, Bi, Cd, Hg, Pb, Te, Th, Tl and U. NAG leach test results indicated a low potential for the leaching of these constituents at near neutral to alkaline pH conditions.

5.4.2.3 Column Test Leachate Results

Bench tailings, combined tailings and bulk ore column leach test results are shown in Tables 5.4-11 to 5.4-13. Results for selected parameters are shown in Figures 5.4-25 to 5.4-52.

The initial leachate pH values (i.e., pore volume 1) for the bulk ore and upper bench tailing samples were 6.2 and 7.4, respectively (Figure 5.4-25). Both samples showed an overall increasing trend in pH values over the period of testing. Leachate pH values for the tailing sample stabilized at approximately 7.8. Ore leachate pH values ranged between approximately 6 and 7. Leachate pH for the combined tailings sample was much more erratic. Leachate pH for this sample generally ranged from 6 to 7.

Similar to the waste rock samples, column leachate conductivity for the two tailings samples decreased significantly during the first few pore volumes (Figure 5.4-26). For the bench upper tailing sample, leachate conductivity stabilized between 80 and 90 micro Siemens per centimeter at the termination of testing. The bench upper tailings leachate conductivity was therefore higher than that measured in the waste rock columns at the termination of testing. Leachate conductivity for the combined tailings sample was significantly higher than for the bench upper tailings sample. Leachate conductivity for the combined tailings declined from 2,385 to 307 micro Siemens per centimeter over the period of testing. Leachate conductivity had not stabilized at the termination of testing but demonstrated a decreasing trend.

The conductivity trend for the ore sample leachate was distinct from the other samples in that a significant decline was not observed during the first few pore volumes (Figure 5.4-26). Leachate conductivity was also much lower for the ore sample than the oxide waste rock and tailing samples. Ore leachate conductivity stabilized at 3 to 6 micro Siemens per centimeter, an order of magnitude lower than bench upper tailings conductivity. The observed differences in conductivity between samples may be attributable to reactive surface area. As shown in Figure 5.1-1, the bulk upper ore sample was coarser than the bench upper tailings and waste rock samples and therefore has a smaller reactive surface area.

Table 5.4-11 Bench Upper Tailings Column Leach Test Results

Parameter	Units	Bench Upper Tailings																				
date		04-May-06	08-May-06	09-May-06	10-May-06	11-May-06	12-May-06	15-May-06	16-May-06	17-May-06	19-May-06	23-May-06	25-May-06	29-May-06	30-May-06	01-Jun-06	5-Jun-06	7-Jun-06	9-Jun-06	12-Jun-06	14-Jun-06	18-Jun-06
pore volume		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
input volume	mL	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640	640
output volume	mL	490	640	645	635	620	630	675	630	620	700	615	625	660	665	620	665	615	630	620	630	635
pH	s.u.	7.42	7.76	7.83	7.87	7.95	7.69	7.91	7.96	7.78	7.80	7.73	7.75	7.71	7.87	7.81	7.80	7.85	7.79	7.82	7.82	7.80
conductivity	µS/cm	443	348	228	146	123	101	96	110	90	89	83	95	85	93	79	81	92	84	80	87	78
alkalinity	mg/L as $CaCO_3$																38	40.32	36.62			
sulfate	mg/L																3	7	5	2.8		4.1
chloride	mg/L																< 0.2	< 0.2	< 0.2	< 0.2		< 0.2
fluoride	mg/L																< 0.05	< 0.05	< 0.05	< 0.05		< 0.05
ortho-phosphorus	mg/L as P																					
hardness	mg/L as $CaCO_3$	196	160	91.7		55.3		44.4		43.3		41.3		38.6		35.3		42.3614		35.6		36.5
Ag	mg/L	< 0.00005	< 0.00005	< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		0.00038		0.0002		< 0.00005
Al	mg/L	0.007	0.003	0.005		0.035		0.06		0.12		0.15		0.17		0.17		0.16		0.22		0.17
As	mg/L	0.033	0.074	0.099		0.11		0.11		0.115		0.105		0.086		0.069		0.073		0.06		0.056
B	mg/L	0.06	0.13	0.17		0.07		0.04		0.03		0.02		0.01		< 0.01		< 0.01		< 0.01		< 0.01
Ba	mg/L	0.369	0.19	0.396		0.285		0.246		0.251		0.22		0.182		0.15		0.174		0.14		0.135
Be	mg/L	< 0.0002	< 0.0002	< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Bi	mg/L	< 0.0002	< 0.0002	< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		0.0002		< 0.0002
Ca	mg/L	76.1	62.4	35.6		21.5		17.4		17.1		16.3		15.3		14		16.8		14.1		14.5
Cd	mg/L	< 0.00004	< 0.00004	< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004		0.00005		< 0.00004		< 0.00004		< 0.00004
Co	mg/L	0.113	0.089	0.059		0.024		0.011		0.0078		0.0053		0.0041		0.003		0.0031		0.0021		0.002
Cr	mg/L	0.0003	0.0003	0.0003		0.001		0.0004		0.0006		< 0.0002		0.0008		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Cu	mg/L	0.018	0.027	0.028		0.027		0.024		0.027		0.025		0.023		0.019		0.019		0.017		0.017
Fe	mg/L	< 0.01	< 0.01	< 0.01		< 0.01		< 0.01		< 0.01		< 0.01		< 0.01		< 0.01		< 0.01		< 0.01		< 0.01
Hg	mg/L	< 0.02	< 0.02	< 0.02		< 0.02		< 0.02		< 0.02		< 0.02		< 0.02		< 0.02		< 0.02		< 0.02		< 0.02
K	mg/L	0.33	0.3	0.25		0.19		0.15		0.14		0.12		0.1		0.09		0.11		0.14		0.1
Li	mg/L	0.0036	0.0039	0.003		0.0018		0.0012		0.0011		0.001		0.0009		0.0007		0.0024		0.0007		0.0007
Mg	mg/L	1.38	1.06	0.67		0.36		0.22		0.17		0.13		0.1		0.08		0.1		0.07		0.07
Mn	mg/L	0.23	0.179	0.117		0.045		0.02		0.015		0.009		0.0068		0.0049		0.0048		0.0031		0.0028
Mo	mg/L	0.057	0.118	0.114		0.043		0.029		0.026		0.024		0.017		0.0095		0.017		0.01		0.011
Na	mg/L	4.34	3.56	2.52		0.88		0.48		0.39		0.31		0.23		0.14		0.17		0.09		0.08
Ni	mg/L	0.0011	0.0009	0.0007		0.0007		0.0003		0.0006		< 0.0002		0.0004		< 0.0002		< 0.0002		< 0.0002		< 0.0002
P	mg/L	0.37	0.86	1.07		1.25		1.06		0.92		0.76		0.56		0.4		0.38		0.31		0.26
Pb	mg/L	< 0.0002	< 0.0002	< 0.0002		0.0006		< 0.0002		0.0002		< 0.0002		< 0.0002		0.0003		0.0003		0.0007		< 0.0002
Rb	mg/L	0.0003	0.0002	0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Sb	mg/L	0.013	0.019	0.024		0.024		0.024		0.024		0.023		0.019		0.015		0.018		0.015		0.015
Se	mg/L	0.0005	0.0008	0.0007		0.0009		0.0012		0.0016		0.002		0.0019		0.0018		0.0023		0.0019		0.0018

Table 5.4-11 Bench Upper Tailings Column Leach Test Results (continued)

Parameter	Units	Bench Upper Tailings																				
date		04-May-06	08-May-06	09-May-06	10-May-06	11-May-06	12-May-06	15-May-06	16-May-06	17-May-06	19-May-06	23-May-06	25-May-06	29-May-06	30-May-06	01-Jun-06	5-Jun-06	7-Jun-06	9-Jun-06	12-Jun-06	14-Jun-06	18-Jun-06
pore volume		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Si	mg/L	21.3	41.4	40.5		49.3		51.3		57.8		55.6		55.2		48.5		50.2		48.5		45.5
Sn	mg/L	0.001	0.0004	0.0005		0.0003		0.0003		0.0003		0.0003		0.0003		0.0003		0.0002		0.0003		0.0002
Sr	mg/L	0.146	0.119	0.1		0.061		0.047		0.045		0.042		0.04		0.036		0.047		0.041		0.041
Te	mg/L	< 0.0002	< 0.0002	< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Th	mg/L	< 0.0001	< 0.0001	< 0.0001		< 0.0001		< 0.0001		0.0001		< 0.0001		0.0001		0.0002		< 0.0001		0.0002		< 0.0001
Ti	mg/L	0.0016	0.0028	0.0028		0.0016		0.0014		0.0015		0.0013		0.0012		0.0012		0.0014		0.0017		0.0012
Tl	mg/L	< 0.00002	< 0.00002	< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002
U	mg/L	< 0.0001	< 0.0001	< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		0.0001		< 0.0001		0.0001		< 0.0001
V	mg/L	< 0.0002	0.0002	0.0002		0.0003		0.0004		0.0006		0.0007		0.0007		0.0008		0.0009		0.0011		0.001
W	mg/L	0.0019	0.005	0.0061		0.015		0.023		0.027		0.025		0.021		0.017		0.016		0.015		0.014
Zn	mg/L	0.029	0.002	0.002		< 0.001		< 0.001		< 0.001		< 0.001		< 0.001		0.007		0.002		0.001		0.001
Zr	mg/L	< 0.002	< 0.002	< 0.002		< 0.002		0.003		0.005		0.006		0.006		0.006		0.004		0.007		0.005

Table 5.4-12 Combined Tailings Column Leach Test Results

Parameter	Units	Combined Tailings																			
date		11-Sep-06	12-Sep-06	13-Sep-06	14-Sep-06	15-Sep-06	18-Sep-06	20-Sep-06	21-Sep-06	22-Sep-06	25-Sep-06	26-Sep-06	27-Sep-06	28-Sep-06	2-Oct-06	3-Oct-06	4-Oct-06	6-Oct-06	10-Oct-06	12-Oct-06	13-Oct-06
cycle		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
input volume	mL	485	485	485	485	485	485	485	485	485	485	485	485	485	485	485	485	485	485	485	485
output volume	mL	430	450	540	460	460	480	490	480	480	480	430	500	490	495	455	520	495	470	490	490
pH	s.u.	6.89	7.26	5.90	7.83	7.12	8.08	7.17	7.87	6.57	7.54	7.22	7.73	7.49	7.47	7.48	8.12	6.36	7.15	7.62	7.28
conductivity	µS/cm	2329	2385	2043	2100	1973	2059	1921	1832	1753	1915	1900	1543	1206	1287	1061	717	521	427	407	307
alkalinity	mg/L as $CaCO_3$	13		13		22		24		23		32		24		38		35.0		48	
sulfate	mg/L	1225		1250		1325		1110		1070		1235		837		538		247		169	
chloride	mg/L	82		15		2		<0.5		<0.5		<0.5		<0.5		<0.5		<0.5		<0.5	
fluoride	mg/L	0.09		0.07		0.10		0.05		0.06		0.03		0.03		0.03		0.04		<0.01	
ortho-phosphorus	mg/L as P	0.06		0.04		0.04		0.04		0.04		0.05		0.07		0.08		0.17		0.2	
hardness	mg/L as $CaCO_3$	1180		1180		1400		1440		1230		1140		716		615		274		208	
Ag	mg/L	0.00075		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005	
Al	mg/L	0.003		0.001		0.002		< 0.001		< 0.001		< 0.001		< 0.001		0.001		0.002		0.002	
As	mg/L	0.021		0.025		0.017		0.037		0.031		0.059		0.02		0.045		0.025		0.036	
B	mg/L	0.06		0.01		0.01		0.01		0.01		< 0.01		0.01		< 0.01		< 0.01		< 0.01	
Ba	mg/L	0.034		0.029		0.03		0.034		0.037		0.042		0.034		0.052		0.033		0.045	
Be	mg/L	< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002	
Bi	mg/L	< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002	
Ca	mg/L	468		464		552		566		487		463		283		240		107		80.2	
Cd	mg/L	0.00005		< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004	
Co	mg/L	0.0051		0.0016		0.0016		0.0018		0.0014		0.0019		0.0009		0.0013		0.0007		0.0009	
Cr	mg/L	< 0.0002		< 0.0002		< 0.0002		0.0002		< 0.0002		0.0005		0.0004		0.0005		0.0006		0.0013	
Cu	mg/L	0.035		0.01		0.0057		0.0052		0.0038		0.0069		0.0043		0.0051		0.0041		0.0058	
Fe	mg/L	0.01		< 0.01		< 0.01		< 0.01		< 0.01		0.74		0.43		< 0.01		< 0.01		0.17	
Hg	mg/L	0.00016		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002	
K	mg/L	12.3		5.71		2.3		1.32		0.93		0.85		0.49		0.55		0.29		0.35	
Li	mg/L	0.035		0.023		0.013		0.012		0.011		0.01		0.0066		0.008		0.004		0.0042	
Mg	mg/L	3.43		5.02		5.43		5.24		3.88		6.59		3.17		3.94		1.53		1.93	
Mn	mg/L	0.0016		0.0004		< 0.0002		0.0003		0.0004		0.0004		< 0.0002		< 0.0002		< 0.0002		0.0016	
Mo	mg/L	0.11		0.069		0.033		0.02		0.013		0.018		0.0082		0.012		0.0077		0.0094	
Na	mg/L	37.2		9.1		0.94		0.46		0.4		0.64		0.25		0.34		0.2		0.31	
Ni	mg/L	0.0022		< 0.0002		< 0.0002		< 0.0002		< 0.0002		0.0004		< 0.0002		< 0.0002		< 0.0002		0.0003	
P	mg/L	0.17		0.15		0.09		0.1		0.08		0.11		0.1		0.14		0.2		0.25	
Pb	mg/L	< 0.0002		0.0006		< 0.0002		< 0.0002		< 0.0002		< 0.0002		0.0004		< 0.0002		< 0.0002		0.0007	
Rb	mg/L	0.015		0.0074		0.0032		0.0016		0.0011		0.0015		0.0009		0.001		0.0005		0.0005	
Sb	mg/L	0.025		0.022		0.017		0.015		0.014		0.017		0.01		0.017		0.014		0.017	
Se	mg/L	0.01		0.0071		0.0058		0.0063		0.0064		0.012		0.0063		0.011		0.0055		0.0073	

Table 5.4-13 Bulk Upper Ore Column Leach Test Results (continued)

Parameter	Units	Combined Tailings																			
date		11-Sep-06	12-Sep-06	13-Sep-06	14-Sep-06	15-Sep-06	18-Sep-06	20-Sep-06	21-Sep-06	22-Sep-06	25-Sep-06	26-Sep-06	27-Sep-06	28-Sep-06	2-Oct-06	3-Oct-06	4-Oct-06	6-Oct-06	10-Oct-06	12-Oct-06	13-Oct-06
cycle		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Si	mg/L	4.27		6.29		6.68		6.44		5.75		7.03		7.35		8.21		8.17		7.95	
Sn	mg/L	0.0012		0.0005		0.0004		0.0003		0.0003		0.0004		0.0004		0.0003		0.0002		0.0002	
Sr	mg/L	1.06		0.963		0.823		0.728		0.633		0.742		0.459		0.405		0.182		0.143	
Te	mg/L	< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002	
Th	mg/L	< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001	
Ti	mg/L	0.0003		0.0003		0.0003		0.0003		0.0003		0.0003		0.0003		0.0003		0.0004		0.0004	
Tl	mg/L	0.00035		0.0002		0.0001		0.00006		0.00004		0.00004		0.00002		< 0.00002		< 0.00002		< 0.00002	
U	mg/L	< 0.0001		0.0001		< 0.0001		0.0001		0.0002		0.0002		< 0.0001		0.0001		< 0.0001		< 0.0001	
V	mg/L	0.0003		0.0003		0.0003		0.0002		0.0002		0.0002		0.0003		0.0003		0.0004		0.0004	
W	mg/L	< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002	
Zn	mg/L	0.017		0.005		< 0.001		< 0.001		0.002		0.002		0.003		< 0.001		0.001		0.003	

Table 5.4-13 Bulk Upper Ore Column Leach Test Results

Parameter	Units	Bulk Upper Ore																				
date		5-Jun-06	6-Jun-06	7-Jun-06	8-Jun-06	9-Jun-06	12-Jun-06	13-Jun-06	14-Jun-06	15-Jun-06	16-Jun-06	19-Jun-06	20-Jun-06	21-Jun-06	22-Jun-06	23-Jun-06	26-Jun-06	27-Jun-06	28-Jun-06	29-Jun-06	30-Jun-06	04-Jul-06
cycle		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
input volume	mL	700	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
output volume	mL	575	360	350	350	350	350	345	350	350	350	325	350	345	350	350	350	350	350	350	355	350
pH	s.u.	6.15	5.90	5.96	6.11	6.39	6.66	6.52	6.55	6.76	6.46	6.79	6.74	6.50	6.25	6.25	6.59	6.34	6.29	6.12	6.31	6.52
conductivity	µS/cm	20	24	18	14	11	13	8	8	7	6	8	5	5	4	3	3	6	5	5	5	6
alkalinity	mg/L as $CaCO_3$	2.9	3.1	3.0	2.6			2.9		2.8		3.1		2.9		2.4		3.3		3.2		2.9
sulfate	mg/L	3	3	<1				<1		<1		<1		<1		<1		<1		<1		<1
chloride	mg/L	1.9	2.41	1.81				0.83		0.52		0.59		0.31		0.2		0.23		< 0.2		0.23
fluoride	mg/L	< 0.05	0.06	< 0.05				< 0.05		< 0.05		< 0.05		< 0.05		< 0.05		< 0.05		< 0.05		< 0.05
ortho-phosphorus	mg/L as P	0.02																				
hardness	mg/L as $CaCO_3$	2.1	3.1	2.9				1.3		1.2		1.4		1.5		0.8		1		0.8		1.1
Ag	mg/L	< 0.00005	< 0.00005	< 0.00005				< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005		< 0.00005
Al	mg/L	0.013	0.007	0.04				0.009		0.012		0.007		0.005		0.005		0.01		0.006		0.006
As	mg/L	0.0005	0.0006	0.0004				0.0005		0.0004		0.0005		0.0003		0.0003		0.0003		0.0002		0.0003
B	mg/L	0.06	0.15	0.13				0.08		0.05		0.06		0.04		0.02		0.03		0.02		0.03
Ba	mg/L	0.0014	0.0039	0.0017				0.0012		0.0012		0.0011		0.0011		0.0006		0.0009		0.0008		0.0009
Be	mg/L	< 0.0002	< 0.0002	< 0.0002				< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Bi	mg/L	< 0.0002	< 0.0002	< 0.0002				< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Ca	mg/L	0.27	0.4	0.47				0.21		0.18		0.21		0.33		0.12		0.16		0.12		0.2
Cd	mg/L	< 0.00004	< 0.00004	< 0.00004				< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004		< 0.00004
Co	mg/L	0.215	0.342	0.256				0.133		0.122		0.15		0.115		0.082		0.109		0.093		0.106
Cr	mg/L	0.0005	0.0004	0.0008				0.0002		< 0.0002		< 0.0002		0.0003		0.0006		< 0.0002		< 0.0002		< 0.0002
Cu	mg/L	0.371	0.65	0.556				0.247		0.242		0.329		0.273		0.21		0.246		0.241		0.237
Fe	mg/L	< 0.01	< 0.01	< 0.01				< 0.01		< 0.01		< 0.01		< 0.01		< 0.01		< 0.01		< 0.01		< 0.01
Hg	mg/L	< 0.00002	< 0.00002	< 0.00002				< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002
K	mg/L	2.78	3.24	2.51				1.39		1.2		1.48		1.12		0.81		1		0.79		0.84
Li	mg/L	0.019	0.075	0.055				0.0085		0.0064		0.0074		0.0046		0.0029		0.0037		0.0026		0.003
Mg	mg/L	0.34	0.51	0.41				0.2		0.17		0.21		0.16		0.12		0.14		0.12		0.14
Mn	mg/L	0.0052	0.0079	0.0055				0.004		0.0034		0.0044		0.0034		0.0025		0.0036		0.0031		0.0037
Mo	mg/L	0.0007	0.0006	0.0007				0.0006		0.0004		0.0006		0.0006		0.0004		0.0004		0.0004		0.0004
Na	mg/L	0.67	0.89	0.66				0.28		0.18		0.2		0.14		0.09		0.11		0.07		0.11
Ni	mg/L	0.0011	0.0015	0.0011				0.0007		0.0004		0.0006		0.0006		0.0006		0.0005		0.0004		0.0005
P	mg/L	< 0.03	0.04	0.04				0.04		< 0.03		< 0.03		< 0.03		< 0.03		0.04		0.03		0.04
Pb	mg/L	< 0.0002	< 0.0002	< 0.0002				< 0.0002		< 0.0002		< 0.0002		0.0015		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Rb	mg/L	0.0032	0.0036	0.0028				0.0013		0.0012		0.0014		0.0011		0.0008		0.001		0.0008		0.0008
Sb	mg/L	< 0.0002	0.0002	0.0002				< 0.0002		< 0.0002		0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Se	mg/L	< 0.0002	< 0.0002	< 0.0002				< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Si	mg/L	1.62	3.28	2.88				2.17		1.82		2.74		1.82		1.21		1.94		1.43		1.52
Sn	mg/L	< 0.0002	< 0.0002	< 0.0002				< 0.0002		< 0.0002		< 0.0002		0.0005		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Sr	mg/L	0.0018	0.0024	0.0019				0.002		0.0015		0.0011		0.0012		0.0006		0.0009		0.0007		0.0009

Table 5.4-13 Bulk Upper Ore Column Leach Test Results (continued)

Parameter	Units	Bulk Upper Ore																				
date		5-Jun-06	6-Jun-06	7-Jun-06	8-Jun-06	9-Jun-06	12-Jun-06	13-Jun-06	14-Jun-06	15-Jun-06	16-Jun-06	19-Jun-06	20-Jun-06	21-Jun-06	22-Jun-06	23-Jun-06	26-Jun-06	27-Jun-06	28-Jun-06	29-Jun-06	30-Jun-06	04-Jul-06
cycle		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Te	mg/L	< 0.0002	< 0.0002	< 0.0002				< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Th	mg/L	< 0.0001	< 0.0001	< 0.0001				< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001
Ti	mg/L	< 0.0002	< 0.0002	0.0002				0.0002		< 0.0002		< 0.0002		0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Tl	mg/L	0.00002	0.00002	< 0.00002				< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002		< 0.00002
U	mg/L	< 0.0001	< 0.0001	< 0.0001				< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001
V	mg/L	< 0.0002	< 0.0002	0.0002				< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		0.0002		< 0.0002		< 0.0002
W	mg/L	< 0.0002	< 0.0002	< 0.0002				< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002		< 0.0002
Zn	mg/L	0.007	0.009	0.009				0.006		0.006		0.006		0.017		0.005		0.005		0.003		0.005
Zr	mg/L	< 0.002	< 0.002	< 0.002				< 0.002		< 0.002		< 0.002		< 0.002		< 0.002		< 0.002		< 0.002		< 0.002

Comparison of the combined tailings column leach test results to the bench upper tailings column leach test results indicates very different behavior. As discussed above, leachate conductivity was much higher for the combined tailings sample than the bench upper sample. Higher conductivity is attributable to higher calcium and sulfate concentrations (Figures 5.4-33 and 5.4-49). For many of the trace metals, combined tailings leachate concentrations were lower than for the bench upper tailings (e.g., Al, Co, Cu, and Mn).

Cobalt concentrations in the first pore volume for the bench upper tailing and ore sample were 0.1 and 0.2 milligrams per liter, respectively. Higher cobalt leaching from the ore is likely in part attributable to its lower leachate pH. Ore cobalt leachate concentrations stabilized at approximately 0.1 milligrams per liter. Tailings cobalt leachate concentrations declined steadily over the period of testing, stabilizing at 3 micrograms per liter (Figure 5.4-36). The combined tailings sample reported lower cobalt leachate concentrations, reporting a peak measured concentration of 5 micrograms per liter (pore volume 1). Combined tailing leachate cobalt concentrations stabilized at a microgram per liter.

Initial copper leachate concentrations were also higher for the ore than the two tailings samples (Figure 5.4-37). Ore copper leachate concentrations peaked at 0.65 milligrams per liter in pore volume two leachates. Between pore volumes 7 and 21, ore leachate concentrations were relatively stable, ranging from 0.21 to 0.33 milligrams per liter. Tailing leachate concentrations were an order of magnitude lower, ranging from 0.02 to 0.03 milligrams per liter in bench upper tailing leachates over the period of testing. Leachate copper concentrations for the combined tailings remained below 0.01 milligrams per liter.

Consistent with SPLP and NAG test results, arsenic leaching was greater from the tailings sample than the ore sample (Figure 5.4-30). Bench upper tailing arsenic leachate concentrations increased from 0.03 to 0.1 milligrams per liter between pore volumes 1 and 3. Bench upper tailings arsenic leachate concentrations remained elevated and relatively stable for the remainder of the testing period, ranging from 0.06 to 0.1 milligrams per liter. Arsenic leachate concentrations for the combined tailings sample ranged from approximately 0.02 to 0.06 milligrams per liter over the period of testing. Ore leachate arsenic concentrations remained below one microgram per liter over the period of testing.

The tailings samples also showed higher antimony, manganese (upper bench only), molybdenum and phosphorus leachate concentrations than the oxide waste rock and ore samples (Figures 5.4-29, 5.4-41, 5.4-42 and 5.4-44, respectively). In the upper bench tailings leachates, leachate concentrations for these parameters typically increased during the first few pore volumes and then gradually declined

over the remainder of the testing period. Ore leachate concentrations for these parameters were comparable or less than the oxide waste rock leachate concentrations.

Chromium, lead and nickel (Figures 5.4-35, 5.4-39 and 5.4-43) concentrations were low in ore and tailings leachates, remaining below 1 microgram per liter. Iron was consistently below detectable limits (less than 0.01 milligrams per liter) in ore and upper bench tailings leachates (Figure 5.4-38). Iron concentrations were also generally low in the combined tailings leachates; however, concentrations on the order of 100s of micrograms per liter were measured on occasion.

Bench upper tailing leachate aluminum concentrations increased over the period of testing stabilizing at approximately 0.2 milligrams per liter (Figure 5.4-28). The combined tailings sample reported very low aluminum concentrations (on the order of a few micrograms per liter). Ore leachate aluminum concentrations were initially higher than the bench upper tailings aluminum leachate concentrations; however, ore aluminum leachate concentrations stabilized at much lower values (less than 0.01 milligrams per liter).

Selenium was present in tailings leachate at microgram per liter levels (Figure 5.4-46). The combined tailings reported higher selenium leachate concentrations than the bench upper tailings. Selenium concentrations in the bench upper tailings leachates stabilized over the period of testing at approximately two micrograms per liter. Selenium was below detectable limits (less than 0.0002 milligrams per liter) in ore leachates.

Zinc leaching was observed from both the tailing and ore samples. Tailings leachate zinc concentrations were typically a few micrograms per liter (Figure 5.4-50). Ore leachate concentrations were consistently higher, stabilizing at approximately 5 micrograms per liter.

Consistent with SPLP and NAG leach test results, the following constituents were typically at or below detectable limits in column test ore and tailing sample leachates: Be, Bi, Cd, Hg, Te, Th and U. Thallium remained at or below detectable limits in the bench upper and ore column leachates. Column leach test results indicated a low potential for the leaching of these constituents under the pH conditions of the column test.

5.4.2.4 Summary Tailings and Ore Metal Leaching

The bench tailings sample slurry was collected following neutralization to a pH value of approximately 7. SPLP, NAG and column leachate pH values for this sample were all near neutral, ranging from 7.4 to 8.0. The bulk tailings sample, which was neutralized to pH 9.0, yielded an SPLP pH of 8.6. The combined tailings sample that was neutralized to a pH of 10, yielded an SPLP pH of 6.4. Leach test results for the tailings are therefore representative of metal leaching under near-neutral to slightly alkaline conditions.

SPLP and column leachate pH values for the bulk ore sample ranged from 5.9 to 7.0. The NAG pH value was higher at 7.9. The ore sample yielded the lowest column pH values (Figure 5.4-25). Unlike the oxide waste rock and tailings sample, dolomite, which provides buffering capacity, is not present in the ore sample.

For some parameters (e.g., Al, Sb, As, Ca, Ba, Mn, Mo, P, Se and Si), column testing showed greater leaching for the bench upper tailings sample in comparison to the ore sample. For some of these parameters, ore sample leachate concentrations were typically lower than the oxide waste leachate concentrations. The lower reactivity of the ore sample is likely in part attributable to its lower surface area (Figure 5.1-1). Column leach test results for the combined tailings sample were distinct from the bench upper tailings sample. Although the combined tailings sample reported similar leachate concentrations for some of the metals listed above (i.e., Sb, As, Mo, P and Se), for some parameters, combined tailings leachate concentrations were lower than those reported for the ore (i.e., Al and Mn).

Leach tests identified a potential for cobalt and copper leaching from the tailings and ore. As would be expected, greater leaching was observed from the ore than from the tailings. The acid leaching conducted as part of the mineral processing will strip the ore of the majority of its leachable copper and cobalt. Column test results for the tailings showed a decline in cobalt leaching over time; whereas the ore column leachates reported stable cobalt concentrations. Copper leaching from the tailings and ore samples was relatively constant over the period of testing.

Leach testing also identified a potential for arsenic leaching from the tailings. Bench upper tailings column test arsenic leachate concentrations peaked at approximately 0.1 milligrams per liter and then declined to 0.06 milligrams per liter at the termination of testing. Arsenic leaching was also observed for the ore sample; however, leachate concentrations from all pore volumes were much lower (less than one microgram per liter) than those for the tailings samples.

Chromium leach test results were variable. Although SPLP and column leach test results indicate a potential for low levels of chromium leaching (leachate concentrations were consistently equal to or less than one microgram per liter), under the oxidizing conditions of the NAG test, greater chromium mobility was observed (i.e., leachate concentrations were orders of magnitude higher at 0.03 milligrams per liter).

Leach test results also showed a potential for phosphorus leaching. Leachate concentrations were higher for the tailings than the ore. The NAG test leachates yielded the highest phosphorus concentrations at 2.5 and 21 milligrams per liter for the bulk ore and bench upper tailings sample, respectively.

Antimony and molybdenum leaching from both tailings and ore were observed. Column test results show a greater potential for leaching of these constituents from the tailings than the ore. The bulk upper tailings sample also showed a higher potential for aluminum and manganese leaching than the ore and combined tailings sample.

The following constituents were typically near or below detectable limits in NAG, SPLP and column test leachates: Be, Bi, Cd, Hg, Te, Th, Tl and U. Leach test results therefore indicate a low potential for the leaching of these constituents at near neutral to alkaline pH conditions.

The following constituents were never detected above microgram per liter levels in test leachates (peak concentration provided in parentheses): Ag (0.0007 milligrams per liter), Ni (0.002 milligrams per liter), Pb (0.002 milligrams per liter), Sn (0.001 milligrams per liter), Ti (0.009 milligrams per liter), V (0.009 milligrams per liter) and Zr (0.007 milligrams per liter). Zinc and selenium leachate concentrations were also typically on the order of a few micrograms per liter or lower. Leach tests therefore identified a potential for low level leaching of these constituents.

5.5 RADIOACTIVITY

A review of all radioactivity data collected as part of the geochemical characterization study was evaluated by Golder personnel with radioactivity expertise. Documentation of this review is provided in Attachment A. This section presents the analytical results as well as a summary of observations. Detailed data interpretation is presented in Appendix B.

5.5.1 Waste Rock

Waste rock radioactivity screening results are shown in Table 5.5-1. It was concluded that special precautions and permitting for the waste rock facilities are not required due to the low levels of radioactivity and the low thorium/uranium concentrations in this material.

5.5.2 Tailings and Ore

Results of radioactivity screening (i.e., gross alpha and gross beta) of samples representative of tailings supernatant and solids and ore solids are shown in Table 5.5-2.

Radioactivity testing indicates a slight potential for low levels of radioactivity associated with tailings waste. The overflow sample collected during flume testing reported a potential for gross alpha activity marginally above the United States Environmental Protection Agency (US EPA) and World Health Organization (WHO) drinking water standards of 0.56 and 0.5 Becquerels per liter, respectively. Samples collected during neutralization of the bulk upper tailings reported lower gross alpha activity.

5.6 TAILINGS SUPERNATANT QUALITY

5.6.1 Tailings Neutralization Test Results

Water chemistry results from neutralization testing of the bench upper tailings sample are shown in Table 5.6-1. These results were provided by Hazen.

Table 5.5-1 Waste Rock Radioactivity Results

Parameter	Units	RAT-OX		SD-OX		RSC-OX		RSF-S		RSC-S		SD-S	
		Result	MDA [(a)]	Result	MDA [(a)]	Result	MDA [(a)]	Result	MDA [(a)]	Result	MDA [(a)]	Result	MDA [(a)]
U-238 decay series													
U-238	Bq/kg	61.5 ± 1.8	1.1	40 ± 1.5	1.1	15.5 ± 0.9	1.1	54.5 ± 1.7	1.1	8.79 ± 0.71	1.1	52.4 ± 1.7	1.1
Ra-226	Bq/kg	**27.7 ± 15.8**	52	-	53	-	42	62.1 ± 12.7	37	-	42	**35.3 ± 12.9**	41
Pb-210	Bq/kg		110	**49.6 ± 23.8**	78	**46.4 ± 17.3**	56	**67.4 ± 20**	63		73	**58.5 ± 21.2**	68
U-235 decay series													
U-235	Bq/kg	2.83 ± 0.09	0.052	1.84 ± 0.07	0.05	0.715 ± 0.043	0.05	2.51 ± 0.08	0.05	0.405 ± 0.033	0.05	2.41 ± 0.08	0.049
Th-232 decay series													
Th-232	Bq/kg	49.1 ± 1.2	3.4	17.2 ± 0.6	2.3	8.53 ± 0.93	3.7	15.1 ± 0.8	4.1	**3.04 ± 0.74**	3	21.3 ± 0.7	3.2
Ra-228	Bq/kg	**52.6 ± 24.6**	79	-	90	-	73	-	80	-	75	-	85
Th-228	Bq/kg	58 ± 13.5	42	**15.8 ± 9.6**	54	**13.9 ± 7.7**	40	-	50	-	43	-	50
Other													
K-40	Bq/kg	942 ± 136	340	510 ± 98	260	**231 ± 74**	230	333 ± 79	220	**231 ± 75**	230	522 ± 88	230
Gross Alpha	Bq/g	1.1 ± 0.14	0.33	0.909 ± 0.132	0.32	**0.277 ± 0.102**	0.31	0.993 ± 0.135	0.32	0.626 ± 0.119	0.31	0.879 ± 0.131	0.32
Gross Beta	Bq/g	1.28 ± 0.02	0.041	0.6 ± 0.019	0.041	0.139 ± 0.014	0.039	0.419 ± 0.017	0.041	0.0967 ± 0.0133	0.04	0.545 ± 0.018	0.041
Uranium	ug/g	4.98 ± 0.15	0.091	3.24 ± 0.12	0.087	1.26 ± 0.07	0.089	4.41 ± 0.14	0.087	0.712 ± 0.058	0.088	4.24 ± 0.13	0.086
Thorium	ug/g	12.1 ± 0.3	0.84	4.23 ± 0.14	0.57	2.1 ± 0.23	0.92	3.73 ± 0.19	1	**0.749 ± 0.182**	**0.74**	5.24 ± 0.18	0.78

[(a)] MDA – minimum detectable activity.

Bolded text identifies range of reported values below the MDA.

Table 5.5-2 Tailing and Ore Gross Alpha and Beta Results

Sample	Sample Source	Units	Gross Alpha	Gross Beta
aqueous analyses				
tailings (bench upper)	flume test overflow	Bq/L	0.61 ± 0.28	0.73 ± 0.14
tailings (bulk upper)	neutralization test (pH 2.6)	Bq/L	0.41 ± 0.23	0.43 ± 0.09
tailings (bulk upper)	neutralization test (pH 8.1)	Bq/L	<0.28	<0.28
solids analyses				
tailings (bench upper)	flume test underflow	Bq/g	0.9 ± 0.33	1.4 ± 0.2
ore (bulk upper)		Bq/g	<0.20	1.4 ± 0.2
tailings (bulk upper)	neutralization test / flume test underflow	Bq/g	0.72 ± 0.27	1.5 ± 0.2
tailings (combined)	pilot test neutralized (pH 10.0)	Bq/g	0.66 ± 0.25	0.88 ± 0.15
FAM	pilot test	Bq/g	0.68 ± 0.26	0.48 ± 0.09

Bq = Becquerel

Table 5.6-1 Bench Upper Tailings Neutralization Test Results

Parameter	Units	Neutralization Test Supernatant			
pH	s.u.	2.90	8.20	8.99	9.98
fluoride	mg/L	<0.2	1.1	1.5	1.4
Dissolved Metals					
Al	mg/L	300	<0.01	<0.01	<0.01
As	mg/L	0.045	0.077	0.086	0.139
Cd	mg/L	0.008	0.008	0.008	0.008
Co	mg/L	32.6	0.98	<0.03	<0.03
Cr	mg/L	<0.02	<0.02	<0.02	<0.02
Cu	mg/L	140	0.075	0.045	0.045
Fe	mg/L	0.855	<0.03	<0.03	<0.03
Hg	mg/L	0.0001	0.0003	<0.00005	<0.00005
Mg	mg/L	3.26	4.06	2.02	0.255
Mn	mg/L	11.4	1.26	0.06	<0.03
Ni	mg/L	0.17	0.06	<0.02	<0.02
Pb	mg/L	<0.08	<0.08	<0.08	<0.08
Se	mg/L	0.002	0.002	0.004	0.006

Water chemistry results from neutralization testing of the bulk upper tailings sample are shown in Table 5.6-2. Due to the similarity in pH values measured by Hazen for the samples with target pH levels of 7 and 8, only one sample was submitted for laboratory analysis. Water chemistry results from neutralization testing of the combined tailings are shown in Table 5.6-3.

Table 5.6-2 Bulk Upper Tailings Neutralization Test Results

Parameter	Units	Neutralization Test Supernatant			
sample ID		FS-2.8	FS-7.5	FS-8.1	FS-9.0
target pH	s.u.		7	8	9
Hazen pH	s.u.	2.78	7.88	7.91	8.44
Hazen conductivity	µS/cm	1855	1548	1550	1418
pH	s.u.	2.60	8.05	-	8.11
conductivity	µS/cm	2085	1731	-	1587
TDS	mg/L	1490	1570	-	1610
TSS	mg/L	36	30	-	42
TOC	mg/L-C	-	-	-	4.69
DOC	mg/L-C	-	-	-	4.81
Anions					
alkalinity	mg/L as $CaCO_3$		160.7	-	72.6
sulfate	mg/L	1003	927	-	893
chloride	mg/L	11.3	11.8	-	11.0
fluoride	mg/L	0.34	0.56	-	0.74
Dissolved Metals					
hardness	mg/L as $CaCO_3$	81.1	1020	-	1010
Ag	mg/L	0.00011	< 0.00005	-	< 0.00005
Al	mg/L	8.41	0.046	-	0.001
As	mg/L	0.111	0.036	-	0.04
B	mg/L	0.01	< 0.01	-	< 0.01
Ba	mg/L	0.032	0.023	-	0.009
Be	mg/L	0.0057	< 0.0002	-	< 0.0002
Bi	mg/L	< 0.0002	< 0.0002	-	< 0.0002
Ca	mg/L	12.2	390	-	398
Cd	mg/L	0.0011	0.00014	-	< 0.00004
Co	mg/L	87.7	26.2	-	0.26
Cr	mg/L	0.026	0.001	-	0.0052
Cu	mg/L	299	0.17	-	0.038
Fe	mg/L	12.5	0.02	-	< 0.01
Hg	mg/L	0.00002	< 0.00002	-	< 0.00002
K	mg/L	3.22	1.14	-	0.64
Li	mg/L	0.052	0.033	-	0.024
Mg	mg/L	12.3	9.89	-	3.81
Mn	mg/L	1.18	0.097	-	0.0016
Mo	mg/L	< 0.0001	0.044	-	0.102
Na	mg/L	13.4	11.3	-	10.5
Ni	mg/L	0.232	0.06	-	0.0016
P	mg/L	2.53	0.09	-	0.35
Pb	mg/L	0.017	< 0.0002	-	< 0.0002
Rb	mg/L	0.0032	0.001	-	0.0006
Sb	mg/L	0.0027	0.0011	-	0.011
Se	mg/L	0.0092	0.0091	-	0.009

Table 5.6-2 Bulk Upper Tailings Neutralization Test Results (continued)

Parameter	Units	Neutralization Test Supernatant			
sample ID		FS-2.8	FS-7.5	FS-8.1	FS-9.0
Si	mg/L	36	70.4	-	74.6
Sn	mg/L	0.0009	< 0.0002	-	0.0002
Sr	mg/L	0.071	0.832	-	0.637
Te	mg/L	< 0.0002	< 0.0002	-	< 0.0002
Th	mg/L	< 0.0001	< 0.0001	-	< 0.0001
Ti	mg/L	0.0032	0.002	-	0.0019
Tl	mg/L	0.00025	0.00002	-	< 0.00002
U	mg/L	0.015	0.0019	-	0.0003
V	mg/L	0.159	0.0005	-	0.0023
W	mg/L	< 0.0002	< 0.0002	-	0.0007
Zn	mg/L	0.21	0.008	-	< 0.001
Zr	mg/L	0.003	< 0.002	-	< 0.002
Total Metals					
hardness	mg/L as $CaCO_3$	75.1	967	-	938
Ag	mg/L	0.00021	< 0.00005	-	< 0.00005
Al	mg/L	8.77	0.051	-	0.072
As	mg/L	0.104	0.036	-	0.039
B	mg/L	0.01	< 0.01	-	< 0.01
Ba	mg/L	0.03	0.023	-	0.0095
Be	mg/L	0.0063	< 0.0002	-	< 0.0002
Bi	mg/L	< 0.0002	< 0.0002	-	< 0.0002
Ca	mg/L	11.5	370	-	369
Cd	mg/L	0.00092	0.00014	-	< 0.00004
Co	mg/L	91.2	25.4	-	0.27
Cr	mg/L	0.024	0.0012	-	0.0053
Cu	mg/L	319	0.196	-	0.071
Fe	mg/L	11.7	0.02	-	0.02
Hg	mg/L	0.00002	< 0.00002	-	< 0.00002
K	mg/L	3.09	1.17	-	0.71
Li	mg/L	0.048	0.036	-	0.027
Mg	mg/L	11.3	10.1	-	3.93
Mn	mg/L	1.04	0.084	-	0.0016
Mo	mg/L	< 0.0001	0.043	-	0.101
Na	mg/L	12.2	11.5	-	10.5
Ni	mg/L	0.218	0.064	-	0.0017
P	mg/L	2.51	0.09	-	0.39
Pb	mg/L	0.016	0.0004	-	0.0002
Rb	mg/L	0.0032	0.0011	-	0.0008
Sb	mg/L	0.0025	0.0012	-	0.011
Se	mg/L	0.0088	0.0092	-	0.0085
Si	mg/L	36.1	68.1	-	68.8
Sn	mg/L	0.0011	< 0.0002	-	0.0003

Table 5.6-2 Bulk Upper Tailings Neutralization Test Results (continued)

Parameter	Units	Neutralization Test Supernatant			
sample ID		FS-2.8	FS-7.5	FS-8.1	FS-9.0
Sr	mg/L	0.067	0.867	-	0.634
Te	mg/L	< 0.0002	< 0.0002	-	< 0.0002
Th	mg/L	0.0002	< 0.0001	-	0.0002
Ti	mg/L	0.01	0.0022	-	0.0055
Tl	mg/L	0.00023	0.00003	-	< 0.00002
U	mg/L	0.014	0.0016	-	0.0003
V	mg/L	0.148	0.0005	-	0.0024
W	mg/L	< 0.0002	< 0.0002	-	0.0006
Zn	mg/L	0.19	0.008	-	0.002
Zr	mg/L	0.004	< 0.002	-	< 0.002
Nutrients					
nitrite	mg/L-N	<0.005	<0.005	-	<0.005
nitrate	mg/L-N	0.07	0.08	-	0.07
nitrate/nitrite	mg/L-N	0.07	0.08	-	0.07
ammonia	mg/L-N	0.08	<0.05	-	<0.05
kjeldahl nitrogen (Calc)	mg/L-N	0.5	0.23	-	0.36
nitrogen (N)	mg/L-N	0.58	0.32	-	0.43
ortho-phosphate	mg/L-P	2.8	0.14	-	0.377

Table 5.6-3 Combined Tailings Neutralization Test Results

Parameter	Units	$Mg(OH)_2$ Supernatant	Neutralization Test Supernatant			
			Pilot (pH 2.8)	Pilot (pH 10)	Flume (pH 9)	Flume (pH 10)
pH	s.u.	5.54	2.85	5.93	6.14	6.15
re-analyzed pH [(a)]	s.u.	-	-	7.55	8.24	8.19
conductivity	µS/cm	4,992	5,849	2,769	2,646	2,259
TDS	mg/L	6,420	8,100	3,130	3,250	2,680
TSS	mg/L	10	313	21	17	34.0
Alkalinity	mg/L as $CaCO_3$	5.8	0.0	15.1	45.0	34.0
Sulfate	mg/L	4,150	5,130	1,820	2,000	1,690
Chloride	mg/L	90.9	72.9	122	13.1	13.3
Fluoride	mg/L	1.16	0.37	0.48	0.48	0.03
Dissolved Metals						
Hardness	mg/L as $CaCO_3$	4.2	3.31	1.61	2.34	1.85
Ag	mg/L	0.0002	<0.00005	<0.00005	<0.00005	<0.00005
Al	mg/L	0.01	19.2	<0.001	0.001	0.002
As	mg/L	0.0019	0.027	0.0066	0.027	0.017
B	mg/L	0.13	0.1	0.01	0.01	0.01
Ba	mg/L	0.11	0.027	0.03	0.013	0.037
Be	mg/L	<0.0002	0.011	<0.0002	<0.0002	<0.0002
Bi	mg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Ca	mg/L	525	486	637	598	696
Cd	mg/L	0.00033	0.0011	<0.00004	<0.00004	<0.00004
Co	mg/L	4.29	185	0.0083	0.024	0.0061
Cr	mg/L	0.0007	0.122	0.0073	0.0031	0.0078
Cu	mg/L	0.034	727	0.023	0.016	0.012
Fe	mg/L	0.02	11.3	<0.01	<0.01	<0.01
Hg	mg/L	0.00002	0.00004	<0.00002	<0.00002	<0.00002
K	mg/L	35.6	24.2	21.7	4.37	4.97
Li	mg/L	0.188	0.177	0.065	0.064	0.047
Mg	mg/L	701	509	4.97	206	27.5
Mn	mg/L	0.138	14.3	0.011	0.0056	0.0041
Mo	mg/L	0.0013	0.0012	0.116	0.281	0.368
Na	mg/L	175	142	111	15.4	16.4
Ni	mg/L	0.005	0.348	0.0023	0.0012	0.001
P	mg/L	<0.03	9.83	<0.03	0.7	0.05
Pb	mg/L	0.0003	0.016	<0.0002	<0.0002	<0.0002
Rb	mg/L	0.107	0.018	0.025	0.0027	0.0038
Sb	mg/L	0.0004	0.0009	0.0088	0.011	0.0096
Se	mg/L	0.028	0.02	0.034	0.024	0.023
Si	mg/L	0.79	38.4	8.33	57.9	33.8
Sn	mg/L	0.0006	0.0005	0.0003	<0.0002	0.0003
Sr	mg/L	4.66	2.1	2.3	1	1.04
Te	mg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002

Table 5.6-3 Combined Tailings Neutralization Test Results (continued)

Parameter	Units	$Mg(OH)_2$ Supernatant	Neutralization Test Supernatant			
			Pilot (pH 2.8)	Pilot (pH 10)	Flume (pH 9)	Flume (pH 10)
Th	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Ti	mg/L	0.0008	0.0037	0.0004	0.0018	0.0011
Tl	mg/L	0.00065	0.0023	0.00024	0.0001	0.0001
U	mg/L	<0.0001	0.049	<0.0001	0.0005	0.0004
V	mg/L	0.0003	0.279	0.0014	0.0026	0.0025
W	mg/L	0.0002	<0.0002	0.0012	0.0012	0.0019
Zn	mg/L	0.01	0.28	0.002	0.002	<0.001
Zr	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002
Total Metals						
Hardness	mg/L as $CaCO_3$	3.86	2.99	1.82	2.08	1.69
Ag	mg/L	0.00018	0.0005	0.00023	<0.00005	<0.00005
Al	mg/L	0.015	15.2	0.21	0.005	0.19
As	mg/L	0.002	0.028	0.0076	0.023	0.014
B	mg/L	0.13	0.08	0.01	<0.01	<0.01
Ba	mg/L	0.105	0.048	0.037	0.011	0.034
Be	mg/L	<0.0002	0.0087	<0.0002	<0.0002	<0.0002
Bi	mg/L	<0.0002	0.0074	0.0006	<0.0002	0.0003
Ca	mg/L	471	441	718	532	633
Cd	mg/L	0.00029	0.001	<0.00004	<0.00004	<0.00004
Co	mg/L	3.98	17.5	0.057	0.019	0.018
Cr	mg/L	0.0005	0.114	0.0092	0.0029	0.0078
Cu	mg/L	0.046	69.9	0.261	0.015	0.04
Fe	mg/L	0.08	12.3	0.25	0.03	0.15
Hg	mg/L	<0.00002	0.00013	<0.00002	<0.00002	<0.00002
K	mg/L	33.6	20.6	25.3	3.86	4.64
Li	mg/L	0.164	0.168	0.097	0.054	0.042
Mg	mg/L	650	459	5.94	183	25.6
Mn	mg/L	0.082	13.8	0.0065	0.0005	0.0009
Mo	mg/L	0.0011	0.0038	0.118	0.269	0.341
Na	mg/L	161	121	124	14.4	15.1
Ni	mg/L	0.0034	0.307	0.0011	0.0005	0.0008
P	mg/L	<0.03	7.55	<0.03	0.6	0.05
Pb	mg/L	0.0004	0.017	<0.0002	<0.0002	<0.0002
Rb	mg/L	0.1	0.018	0.025	0.0025	0.0037
Sb	mg/L	<0.0002	0.0009	0.01	0.0089	0.0083
Se	mg/L	0.023	0.016	0.03	0.018	0.017
Si	mg/L	0.77	37.7	10.7	48.7	30.9
Sn	mg/L	0.0007	0.001	0.0005	<0.0002	0.0003
Sr	mg/L	4.32	2.02	2.24	0.963	0.959
Te	mg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Th	mg/L	<0.0001	0.0011	<0.0001	<0.0001	<0.0001

Table 5.6-3 Combined Tailings Neutralization Test Results (continued)

Parameter	Units	$Mg(OH)_2$ Supernatant	Neutralization Test Supernatant			
			Pilot (pH 2.8)	Pilot (pH 10)	Flume (pH 9)	Flume (pH 10)
Ti	mg/L	0.0015	0.014	0.0018	0.0015	0.0018
Tl	mg/L	0.0006	0.0022	0.00028	0.0001	0.0001
U	mg/L	<0.0001	0.046	<0.0001	0.0004	0.0004
V	mg/L	0.0003	0.25	0.0026	0.0025	0.0029
W	mg/L	<0.0002	<0.0002	0.0013	0.0011	0.0017
Zn	mg/L	0.005	0.24	0.002	<0.001	0.004
Zr	mg/L	<0.002	0.009	<0.002	<0.002	<0.002
Nutrients						
Nitrate plus Nitrite (N)	mg/L-N	1.1	1.39	1.26	0.3	0.45
Ammonia	mg/L-N	0.14	0.475	0.076	0.025	<0.005
Kjeldahl Nitrogen (Calc)	mg/L-N	0.78	1	0.78	0.52	0.59
Nitrogen (N)	mg/L-N	1.88	2.4	2.04	0.82	1.04
Ortho-phosphate (P)	mg/L as P	0.014	23.4	0.007	0.72	0.062
TOC	mg/L-C			4.81		
DOC	mg/L-C			4.08		

(a) Reported pH values for the neutralized samples were lower than expected. Golder requested that CEMI re-analyze pH. Reanalysis resulted in higher pH values.

The starting pH values for neutralization testing of the bench upper, bulk upper and combined tailings samples were all similar, ranging from 2.6 to 2.9. Cobalt and copper concentrations were higher (by a factor of greater than two) in the acidic bulk upper tailings supernatant in comparison to the bench upper tailings supernatant. Differences in bench and bulk supernatant concentrations prior to neutralization were observed for aluminum, iron and manganese. The combined tailings sample reported the highest copper and cobalt concentrations prior to neutralization at 727 and 185 milligrams per liter, respectively.

Neutralization of tailings supernatant typically results in following changes to water quality:

Concentration Increase: alkalinity, Ca, F, Mo, Sb and Si; and,

Concentration Decrease: Ag, Al, Be, Cd, Co, Cr, Cu, Fe, Mg, Mn, K, Na, Ni, P, Pb, SO_4, Tl, U, V and Zn.

The following constituents reported relatively stable concentrations during neutralization: B, Cl (combined tailings are an exception), Hg and Se. Arsenic concentration trends were inconsistent between the three tests. Neutralization of the bench upper tailings resulted in an increase in supernatant arsenic concentrations, whereas neutralization of the bulk upper tailings resulted in a decrease in supernatant arsenic concentrations. Neutralization of the combined tailings resulted in a decrease (pH 10 samples) or no change (pH 9 sample) in dissolved arsenic concentrations.

Increases in calcium and alkalinity concentrations during neutralization are attributed to the dissolution of the limestone and/or lime used to raise the pH. Increases in molybdenum and selenium concentrations as pH increases are consistent with the geochemical behavior of these elements, which exhibit greater mobility at higher pH.

The observed decline in sulfate concentrations during neutralization may be attributable to precipitation of gypsum. Speciation modeling indicates that the neutralized solutions are near equilibrium with respect to gypsum. Attenuation of iron and aluminum during neutralization is attributed to mineral precipitation, likely iron and aluminum (oxy)hydroxides. Precipitation of iron and aluminum (oxy)hydroxides will likely result in metals attenuation by adsorption or co-precipitation. The observed declines in concentrations for a number of metals are likely attributable to this mechanism (e.g., Ag, Cd, Cr, Ni, Pb and Zn). Attenuation of copper and cobalt during neutralization is likely due to mineral precipitation (i.e., carbonates and/or hydroxides) and adsorption onto iron (oxy)hydroxides.

Neutralization consistently effectively reduces cobalt and copper concentrations to below a milligram per liter. The 26 milligrams per liter cobalt concentration measured in the bulk upper tailings sample at pH 7.5 is anomalous (Table 5.6-2), and this result in not considered representative of the expected cobalt concentrations in discharge to the TSF.

Water chemistry results for overflow from the bench upper tailings flume test are shown in Table 5.6-4. Because manganese was added during the leach process, reported concentrations for this constituent are not considered representative of supernatant quality.

Table 5.6-4 Bench Upper Tailings Flume Test Overflow (O/F) Water Quality

Parameter	Units	Bench Upper Tailings Flume Test Overflow (O/F)	
pH	s.u.	8.3	
conductivity	µS/cm	1338	
TDS	mg/L	1200	
TSS	mg/L	50	
alkalinity	mg/L as $CaCO_3$	180	
sulfate	mg/L	520	
chloride	mg/L	10.8	
fluoride	mg/L	0.63	
TOC	mg/L-C	3.74	
DOC	mg/L-C	4.39	
BOD	mg/L	<10	
COD	mg/L	<10	
Color	mg/L	<5	
silica (reactive)	mg/L	93	
Nutrients			
nitrate/nitrite	mg/L-N	0.47	
ammonia	mg/L-N	0.016	
kjeldahl nitrogen (Calc)	mg/L-N	0.32	
nitrogen	mg/L-N	0.79	
Metals		**Dissolved**	**Total**
hardness	mg/L as $CaCO_3$	705	723
Ag	mg/L	< 0.00005	< 0.00005
Al	mg/L	0.003	0.009
As	mg/L	0.0083	0.011
B	mg/L	< 0.01	< 0.01
Ba	mg/L	0.019	0.019
Be	mg/L	< 0.0002	< 0.0002
Bi	mg/L	< 0.0002	< 0.0002
Ca	mg/L	272	279
Cd	mg/L	< 0.00004	< 0.00004
Co	mg/L	5.58 (a)	8.89 (a)
Cr	mg/L	0.0008	0.0015
Cu	mg/L	0.0033	0.019
Fe	mg/L	< 0.01	0.02
Hg	mg/L	< 0.00002	< 0.00002
K	mg/L	0.51	0.52
Li	mg/L	0.0088	0.0088
Mg	mg/L	6.08	6.01
Mn	mg/L	5.26 [(a)]	6.77 [(a)]
Mo	mg/L	0.111	0.123
Na	mg/L	11.7	11.5
Ni	mg/L	0.046	0.063

Parameter	Units	Bench Upper Tailings Flume Test Overflow (O/F)	
P	mg/L	< 0.03	0.04
Pb	mg/L	< 0.0002	< 0.0002
Rb	mg/L	0.0005	0.0005
Sb	mg/L	0.0007	0.0007
Se	mg/L	0.0021	0.0023
Si	mg/L	40.9	43
Sn	mg/L	< 0.0002	< 0.0002
Sr	mg/L	0.466	0.46
Te	mg/L	< 0.0002	< 0.0002
Th	mg/L	< 0.0001	< 0.0001
Ti	mg/L	0.0012	0.0017
Tl	mg/L	< 0.00002	< 0.00002
U	mg/L	0.0008	0.0009
V	mg/L	< 0.0002	< 0.0002
W	mg/L	0.0012	0.0013
Zn	mg/L	0.001	0.005
Zr	mg/L	< 0.002	< 0.002

[(a)] Sample concentration elevated due to addition during testing.

Flume test overflow water quality results were generally similar to water quality results for the neutralization test samples.

5.6.2 Tailings Stability Test Results

To evaluate the stability of the upper bulk neutralized tailings following atmospheric interaction, CEMI monitored the pH and conductivity of tailings slurry supernatant over a one-month period (Figure 5.6-1). Over the first two weeks, pH and conductivity were recorded daily (Monday to Friday). The frequency of measurements was then increased to weekly.

The pH of the tailings supernatant declined from 8.6 to 8.2 within the first two weeks. Supernatant pH remained relatively stable over the remainder of the test, ranging from 8.2 to 8.3. This pH value is likely representative of equilibrium with respect to calcite in an open system (i.e., under atmospheric CO_2 conditions). Coincident with a decline in pH, supernatant conductivity increased from approximately 1,330 to 1,890 micro Siemens per centimeter. Because the observed increase in conductivity suggested leaching from the tailings solids to the supernatant, a supernatant sample was collected at 35 days and submitted for analysis.

Supernatant results are shown in Table 5.6-5. For comparison, this table also shows the chemistry of the supernatant during neutralization. The final column presents the change (percent) between concentrations in supernatants from the final neutralization test sample (i.e., pH 8.11) vs. the stability test sample. Non-detect values were assumed equal to the detection limit in calculation of percentage change. Changes that are considered statistically significant (i.e., greater than analytical accuracy) are shown in bold type. A change was considered statistically significant if it was greater than 20 percent for results greater than five times the laboratory detection limit. For results less than five times the laboratory detection limit, a change was considered significant if it was greater than five times the laboratory detection limit.

Stability test supernatant water quality results show little metals remobilization following a decline in supernatant pH and increase in conductivity. Statistically significant reductions in both dissolved copper and cobalt concentrations were observed relative to the final neutralization test sample. Chromium, manganese, nickel and selenium concentrations also decreased.

The following metals reported statistically significant increases in concentration: Ba (15 micrograms per liter), Cd (0.35 micrograms per liter), Li (20 micrograms per liter) and Mo (229 micrograms per liter).

Table 5.6-5 Upper Bulk Tailings Stability Test Supernatant Results

Parameter	Units	Neutralization Study			Stability Test	% Change[(a)]
pH	s.u.	2.60	8.05	8.11	7.99	-1
conductivity	µS/cm	2,085	1,731	1,587	1,775	12
TDS	mg/L	1,490	1,570	1,610	1,760	9
Anions						
alkalinity	mg/L as $CaCO_3$		160.7	72.6	92.4	27
sulfate	mg/L	1,003	927	893	1,035	16
chloride	mg/L	11.3	11.8	11.0	14.2	29
fluoride	mg/L	0.34	0.56	0.74	0.51	-31
Dissolved Metals						
hardness	mg/L as $CaCO_3$	81.1	1020	1010	979	-3
Ag	mg/L	0.00011	< 0.00005	< 0.00005	< 0.00005	0
Al	mg/L	8.41	0.046	0.001	0.001	0
As	mg/L	0.111	0.036	0.04	0.044	10
B	mg/L	0.01	< 0.01	< 0.01	< 0.01	0
Ba	mg/L	0.032	0.023	0.009	0.024	167
Be	mg/L	0.0057	< 0.0002	< 0.0002	< 0.0002	0
Bi	mg/L	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0

Table 5.6-4 Upper Bulk Tailings Stability Test Supernatant Results (continued)

Parameter	Units	Neutralization Study			Stability Test	% Change[(a)]
Ca	mg/L	12.2	390	398	388	-3
Cd	mg/L	0.0011	0.00014	< 0.00004	0.00039	875
Co	mg/L	87.7	26.2	0.26	0.015	-94
Cr	mg/L	0.026	0.001	0.0052	0.0024	-54
Cu	mg/L	299	0.17	0.038	0.025	-34
Fe	mg/L	12.5	0.02	< 0.01	< 0.01	0
Hg	mg/L	0.00002	< 0.00002	< 0.00002	< 0.00002	0
K	mg/L	3.22	1.14	0.64	0.77	20
Li	mg/L	0.052	0.033	0.024	0.044	83
Mg	mg/L	12.3	9.89	3.81	2.04	-46
Mn	mg/L	1.18	0.097	0.0016	0.0003	-81
Mo	mg/L	< 0.0001	0.044	0.102	0.331	225
Na	mg/L	13.4	11.3	10.5	11.2	7
Ni	mg/L	0.232	0.06	0.0016	0.0004	-75
P	mg/L	2.53	0.09	0.35	0.1	-71
Pb	mg/L	0.017	< 0.0002	< 0.0002	< 0.0002	0
Rb	mg/L	0.0032	0.001	0.0006	0.0008	33
Sb	mg/L	0.0027	0.0011	0.011	0.014	27
Se	mg/L	0.0092	0.0091	0.009	0.0039	-57
Si	mg/L	36	70.4	74.6	57.3	-23
Sn	mg/L	0.0009	< 0.0002	0.0002	< 0.0002	0
Sr	mg/L	0.071	0.832	0.637	0.645	1
Te	mg/L	< 0.0002	< 0.0002	< 0.0002	< 0.0002	0
Th	mg/L	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0
Ti	mg/L	0.0032	0.002	0.0019	0.002	5
Tl	mg/L	0.00025	0.00002	< 0.00002	0.00003	50
U	mg/L	0.015	0.0019	0.0003	0.0005	67
V	mg/L	0.159	0.0005	0.0023	0.0019	-17
W	mg/L	< 0.0002	< 0.0002	0.0007	0.0007	0
Zn	mg/L	0.21	0.008	< 0.001	0.003	200
Zr	mg/L	0.003	< 0.002	< 0.002	< 0.002	0
Nutrients						
nitrate/nitrite	mg/L-N	0.07	0.08	0.07	0.04	-43
ammonia	mg/L-N	0.08	<0.05	<0.05	<0.005	0
kjeldahl nitrogen	mg/L-N	0.5	0.23	0.36	0.31	-14
nitrogen	mg/L-N	0.58	0.32	0.43	0.36	-16
ortho-phosphate	mg/L-P	2.8	0.14	0.377	0.168	-55

[(a)] Percentage change between final neutralization test sample (i.e., pH 8.11) and stability test sample. Non-detect values assumed equal to the detection limit in calculation of percentage change.

6 PREDICTION OF MINE WATER QUALITIES

6.1 INTRODUCTION

The results of the geochemical characterization program were used to predict mine water qualities during operations and post-closure. This chapter presents the approach and results for the prediction of Kwatebala waste rock facility runoff and seepage, ore stockpile runoff and seepage, pit lake water quality and tailings supernatant quality. In all cases, prediction of mine water qualities applied geochemical characterization results representative of waste and ore from the oxide portion of the ore body. The water quality predictions presented in this document are therefore only applicable to mining and processing of the oxide ore body.

6.1.1 Model Selection

The prediction of mine water qualities included geochemical modeling. The geochemical model used in this study was PHREEQC Version 2.12 (Parkhurst and Appelo 1999), an equilibrium speciation and mass-transfer code developed by the United States Geological Survey (USGS). This model has the ability to simulate the pertinent processes occurring in mine waste facilities, such as mixing of multiple solutions, precipitation/dissolution of selected solids, redox reactions, evaporation, atmospheric interaction, and adsorption of metals. PHREEQC was chosen because it combines the thermodynamic and adsorption capabilities of MINTEQA2 with the ability to conduct mixing and reaction path modeling. The reaction path portion of PHREEQC performs mass-balance calculations while keeping track of the total concentrations of each element in the solution and solid phases. The MINTEQA2 database (minteq.V4.dat) was applied.

6.1.2 Copper and Cobalt Mobility

Copper and cobalt in the oxide ore body principally occur as malachite [$Cu_2CO_3(OH)_2$] and heterogenite [CoOOH]. A description of the ore minerals is presented in Section 3.1. The potential for release of copper and cobalt from mine wastes will therefore be dependent on the environmental stability of these mineral phases. Following release, copper and cobalt attenuation may occur due to precipitation of secondary mineral phases and/or sorption processes. Because the geochemical controls on copper and cobalt release and attenuation are likely to be similar for all waste facilities, a general discussion of controls on their mobility follows.

As shown in Figure 6.1-1, the solubility of malachite is pH dependent. Malachite is least soluble at slightly alkaline pH values (i.e., between pH 8.5 and 9.5). As conditions become more acidic, malachite solubility increases resulting in higher aqueous copper concentrations. Malachite is a common solubility control for copper (e.g., Nordstrom and Alpers 1999). Therefore, within the waste rock facilities and ore stockpiles, dissolved copper concentrations in seepage will likely reflect equilibrium with malachite. Under alkaline pH values, aqueous copper concentrations may be reduced by the precipitation of copper hydroxide. This secondary mineral control will likely dominate above a pH of approximately 9 (i.e., the intersection pH of the malachite and copper hydroxide solubility curves in Figure 6.1-1). Between pH 6 and 9, if secondary mineral controls are effective, peak aqueous copper concentrations would be expected to range from milligram per liter (pH 6) to micrograms per liter (pH 9).

Given the fact that heterogenite is a relatively unusual mineral, its thermodynamic data are not available in the PHREEQC databases. A solubility curve for this mineral phase was therefore not generated. Solubility curves for two other cobalt phases, sphaerocobaltite and cobalt hydroxide, are shown in Figure 6.1-2. Two solubility curves are shown for sphaerocobaltite. These curves were derived from published thermodynamic data for this cobalt carbonate phase. The upper curve (corresponding to a log K value of -9.98) represents the thermodynamic data included in database applied in this study (minteq.V4.dat). The lower curve (corresponding to a log K value of -12.13) represents thermodynamic data published in Garrels and Christ (1965). This figure illustrates the uncertainty in the solubility product of the cobalt carbonate phase. A key assumption in any geochemical modeling effort is that the available thermodynamic data are accurate. Derivation of thermodynamic data for cobalt has received less attention than other elements. As such, there is more uncertainty inherent in use of models to predict the behavior of cobalt in the environment. For the current study, the upper solubility curve for sphaerocobaltite was adopted, which represents an environmentally-protective approach (i.e., predicted cobalt concentrations are biased high).

Similar to copper, as pH decreases, aqueous cobalt concentrations are expected to increase. Under near neutral to slightly alkaline pH values, cobalt carbonate is the most likely control on aqueous cobalt concentrations. Above pH 9, cobalt hydroxide may control aqueous cobalt concentrations. Between pH 6 and 9, if secondary mineral controls are effective, peak aqueous cobalt concentrations would be expected to range from tens of milligrams per liter (pH 6) to hundreds of micrograms per liter (pH 9) (assuming the upper cobalt carbonate solubility curve is most representative of cobalt behavior).

Dolomite is the main carbonate mineral present in the host rock. The dolomite solubility curve is shown in Figure 6.1-3. As pH decreases, dolomite solubility increases. Between pH 6 and 9, aqueous magnesium concentrations under dolomite equilibrium would be expected to range from hundreds of milligrams per liter (pH 6) to milligrams per liter (pH 9).

6.1.3 Model Assumptions

Use of geochemical modeling to predict mine water qualities necessarily requires use of assumptions due to the general inability to unequivocally determine the physical and geochemical characteristics of the complex systems being modeled, particularly in the case where the waste facilities do not yet exist (e.g., waste rock facility, tailings pond and pit lake). Assumptions applicable to each particular facility are listed at the end of their respective sections. General assumptions inherent to the prediction of water qualities for all waste facilities are as follows:

- The water chemistries used in the modeling are representative of their respective input sources. This assumption is a sine qua non; without this assumption, it is not possible to proceed with water qulaity modeling. Input water qualities were developed using results of the geochemical characterization program.
- The application of lab-scale leach test results to predict the magnitude of field-scale leaching is not a straightforward task. Metal leaching at the field scale will likely be variable through time and will be controlled by a number of factors which may not be captured or accurately represented at the lab scale. These factors include the weathering environment (e.g., temperature, nature of the lixiviant), the interaction between the solution and solid (e.g., solution to solid ratio and contact/reaction time) and considerations related to physical characteristics of the mine waste, such as particle size and texture. Standard practices were applied in the application of laboratory results to predict field scale processes.
- Modeled waters are in full thermodynamic equilibrium. The equilibrium assumption is the standard computational basis of PHREEQC, although kinetic considerations can be taken into account should this be deemed critical. On a detailed scale, such equilibrium is unlikely to be the case for all chemical components throughout all mine waters. However, geochemical evaluations of natural and mine waters over the last few decades have shown that the equilibrium assumption is a powerful tool that in many circumstances produces results that accurately describe the nature of the general chemistry of such waters.
- The PHREEQC model appropriately simulates chemical reactions and contains the appropriate thermodynamic constants.

- Precipitation of credible mineral phases may limit dissolved phase concentrations. Geochemical model simulations included an evaluation of the potential for mineral controls to limit dissolved phase concentrations. Following conservative mixing, speciated solution chemistries were evaluated. A large number of geochemically-credible supersaturated mineral phases were identified and assessed for their likelihood to precipitate from the solution. The selection of geochemically-credible mineral phases was based on the occurrence of these minerals at other mining sites (e.g., Nordstrom and Alpers 1999). Observations of these phases in mine-waste environment suggest that kinetic impediments to precipitation of these phases are not significant.
- Dissolved phase metals concentrations were modeled: Dissolved phase results were applied to define input water qualities for geochemical modeling as the dissolved fraction represents the geochemically-reactive component in aqueous environments. Predicted water qualities are therefore representative of dissolved phase concentrations. Total metal concentrations have not been predicted (i.e., the particulate metals load in waste rock runoff due to mobilization of fines).
- Leach test results from the Knight Piésold and current geochemical characterization programs were used to predict mine water qualities. Derivation of input water qualities for geochemical modeling assumed that concentrations reported as below detectable limits in leach test results were equal to the detection limit. This assumption may, in some cases, result in estimates of mine water concentrations that are biased high. Use of scaling factors to adjust measured laboratory leachate concentrations to the field scale may also result in biased high estimates for constituents reported as below detectable limits. It should be noted that detection limits for some constituents differ between the Knight Piésold and current characterization programs. For some constituents, detection limits also varied within the current program due to the use of different laboraotries. In the presentation of model results, predictions based on detection limit values have been identified.

It is important to note that the goal of water quality predictions is to present a likely range of mine water qualities rather than unique compositions to assess the potential for impacts to groundwater and surface water resources. Due to the assumptions and inherent limitations of predictive modeling, results should be considered as order of magnitude estimates. Concentrations that are predicted to be below one microgram per liter are presented as such (i.e., less than 0.001 milligrams per liter) without further quantification.

In the assessment of potential environmental impacts, predicted mine water qualities are typically compared to relevant water quality standards and guidelines. Direct comparison of predicted mine water quality predictions to applicable standards must consider the expected accuracy of the predictions (i.e., order of magnitude). Also, the use of detection limit values in the prediction of mine water qualities (which may result in concentrations that are biased high) must be considered.

6.2 WASTE ROCK

6.2.1 Introduction

The Kwatebala deposit is estimated to contain approximately 80 million tonnes of oxide ore (Section A4 – Table A4.1-3). The Goma and Fwaulu or bodies are estimated to contain approximately 17 and 6 million tonnes of oxide ore, respectively. Mining of all three deposits is expected to generate approximately 225 million tonnes of waste rock. The main waste rock facility is the Kwatebala waste rock facility. This facility has been designed to accommodate waste extracted during mining of the Kwatebala and Fwaulu ore reserves. The design height and footprint of the facility are 100 meters and 145 hectares, respectively. Goma waste rock will be directed to the Goma waste rock facility.

The ESIA addresses mining and processing of only the Kwatebala oxide ore. Estimated annual waste rock and ore production for years 2007 through 2027 for all three ore bodies are shown in Figure 6.1-4. During approximately the first eight years of mining (2008 to 2016), only the Kwatebala oxide ore deposit will be developed. In 2017 and 2020, development of the Goma and Fwaulu oxide ore bodies will begin.

Production and development of the Kwatebala deposit will be by conventional drill and blast methods. Rock will be blasted with explosives so that it can be broken up and removed. Ammonium nitrate/fuel oil (or used oil) mixture (ANFO) will be utilized as the principal blasting agent. Waste rock will be transported by truck to the Kwatebala waste rock facility.

This section presents the approach and results for the prediction of waste rock runoff and seepage quality for the Kwatebala waste rock facility. Prediction of Kwatebala waste rock facility runoff and seepage assumed that all waste rock generated in the first 13 years of mining reports to the Kwatebala waste rock facility. This represents a simplification of the current mine plan. The mass of waste rock within the facility was therefore estimated to be 142 million tonnes at year 2020. The predictions are therefore representative of expected water

qualities during the first 13 years of mining (2007 to 2020), assuming development of only the oxide ore body. The distribution of waste by rock type for the Kwatebala pit is estimated to be as follows: 68 percent SD, 5 percent RSC and 27 percent RAT.

The quality of waste rock seepage and runoff will primarily be a function of the following:

- The composition of the waste rock facility (i.e., the relative proportions of the different oxide waste rock classes within the facility).
- The reactivity (or stability) of the waste rock and the interaction between the waste rock and recharge (i.e., the solution to solids ratio and amount of contact time between waste rock runoff/seepage and waste rock).

The prediction of waste rock seepage and runoff quality made use of the results from the waste rock water balance to define the physical system. Results from the waste rock geochemical characterization program were used to predict metal leaching.

6.2.2 Model Approach and Methodology

6.2.2.1 Overview

The general modeling sequence followed the steps listed below:

1. ***Define waste rock facility composition.*** The physical properties of the waste rock facility (i.e., height, surface area and waste rock tonnage) and the composition of the waste rock facility were compiled.
2. ***Define input water qualities.*** Waste rock seepage and runoff input chemistries were estimated for each of the three oxide waste rock classes (SD, RSC and RAT). Estimates of waste rock seepage and runoff water qualities were derived from column leach test and SPLP leach test results, respectively. To estimate metal leaching at the field scale from laboratory leach test results, both mass loading and surface area loading approaches were used. A range of input water qualities was defined for both waste rock runoff and seepage.
3. ***Conservative water quality estimate.*** Input water qualities derived for each of the three oxide waste rock classes were mixed in appropriate ratios, based on their relative proportions within the facility, and the resultant seepage or runoff water composition determined.
4. ***Consideration of geochemical controls.*** The conservative seepage or runoff water compositions were used as inputs for geochemical modeling

in PHREEQC. The geochemical modeling included an evaluation of metals speciation, redox (Eh), pH, alkalinity, and saturation indices for mineral phases. Supersaturated mineral phases were identified and assessed for their likelihood to precipitate from the solution. The effect of equilibrium with appropriate atmospheric gases (i.e., carbon dioxide) was evaluated. After equilibration with the selected solid phases and carbon dioxide, the solution composition was determined anew.

5. ***Estimation of nitrogen loading***. Prediction of nitrogen concentrations in seepage and runoff assumed a source from residual products of blasting agents (i.e., ANFO).

Each of these steps is described in more detail in the following sections.

6.2.2.2 Waste Rock Facility Composition

Prediction of waste rock seepage and runoff water qualities was based on the properties of the waste rock facility following mining of only the oxide ore reserve, as follows:

- Waste rock tonnage - 142 million tonnes (years 2007 to 2020).
- Maximum waste rock facility height – 100 meters.
- Waste rock facility footprint – 145 hectares.

Oxide waste rock has been subdivided into three waste rock classes (i.e., SD, RSC and RAT). The estimated distribution of waste by rock type for the Kwatebala pit is shown in Table 6.2-1. Prediction of waste rock facility water qualities assumed a final facility composition of these proportions. The estimated proportion of RSC waste is lower than that estimated by Knight Piésold (1998) for the Kwatebala pit (5 percent versus 31 percent). This apparent difference is due to the fact that much of the ore occurs in the RSC unit and therefore does not report to the waste rock facility.

Table 6.2-1 Oxide Waste Rock Proportions

Oxide Waste Rock Class	Description	Percentage of Waste Rock in Kwatebala Pit (wt. %)[a]
SD	dolomitic shales	68
RSC	silicified stromatolitic dolomite	5
RAT	chloritic, dolomitic pelites and siltstones	27

[a] Waste distribution provided by M. Pagel of Phelps Dodge (email communication October 25, 2006). Distribution calculation excludes the component of CMN and Dipeta waste. Calculation assigns the RSF waste to the RSC waste rock type and the SBD waste to the SD waste rock type.

6.2.2.3 Waste Rock Facility Water Balance

The waste rock facility water balance is presented in the Feasibility Study (MinProc 2007). Assuming a mean annual precipitation (MAP) of 1,200 millimeters, 264 millimeters is predicted to report as seepage at the toe of the waste rock facility or as seepage to groundwater (Table 6.2-2). For a footprint of 145 hectares, this equates to approximately 382,000 cubic meters of seepage annually.

Table 6.2-2 Waste Rock Facility Water Balance

	Depth (mm)	Percentage of MAP
mean annual precipitation (MAP)	1,200	
runoff	254	21
seepage (toe seepage and seepage to groundwater)	264	22

The seepage travel time through the waste rock facility is estimated at approximately one to three months (Feasibility Study – MinProc 2007). This means that water recharged through the top of the waste rock facility is predicted to exit from the toe or base of the facility between approximately 30 and 90 days.

6.2.2.4 Input Water Qualities – Waste Rock Facility Runoff

Short-term SPLP leach test results were used to define a range of representative waste rock runoff water qualities. The conditions of the SPLP leach test are considered most representative of the interaction between rainwater and waste rock as this test was designed to assess the environmental stability of a waste material following relatively short-term contact with meteoric water. SPLP leach test results for waste rock samples were presented in Tables 5.4-2 and 5.4-3.

Prediction of waste rock runoff quality assumed that SPLP leachate concentrations are representative of the amount of a metal that will be leached from solids suspended in waste rock runoff. The SPLP leach tests applied a 20 to 1 liquid to solid ratio by weight (2,000 milliliters of water to 100 grams of solid). SPLP leachate concentrations (in milligrams per liter) were assumed representative of waste rock runoff concentrations. A 20 to 1 liquid to solid ratio is equivalent to a total suspended solids (TSS) concentration of 50,000 milligrams per liter. Because the TSS of waste rock runoff is expected to be less than this value, direct use of SPLP concentrations without application of a scaling factor was considered conservative. For each of the three oxide waste rock classes, results for all constituents from the eight SPLP tests were averaged

to define an average loading rate. The maximum and minimum loading rates for each constituent were also determined. The range of waste rock runoff input water qualities, for each waste rock class, is shown in Table 6.2-3.

Table 6.2-3 Waste Rock Runoff Input Water Qualities

Loading Rate		Average			Maximum			Minimum		
Oxide Waste Rock Class		SD	RSC	RAT	SDS	RSC	RAT	SD	RSC	RAT
pH [d]	s.u.	8.8	8.4	7.2	6.5	6.4	6.2	9.4	9.8	9.1
alkalinity	mg/L as $CaCO_3$	70	42	30	265	223	154	33	7.0	1.0
TDS [a]	mg/L	137	93	66	519	397	295	62	22	5.4
Ag	mg/L	0.003	0.003	0.003	0.003	0.003	0.003	0.001	0.001	0.001
Al	mg/L	0.05	0.09	0.2	0.2	0.3	0.8	0.001	0.02	0.001
As [c]	mg/L	0.003	0.003	0.004	0.007	0.006	0.01	0.001	0.001	0.001
Ba	mg/L	0.01	0.09	0.1	0.06	0.3	0.8	0.002	0.002	0.002
Be	mg/L	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ca	mg/L	17	11	6.1	64	47	28	5.8	2.6	0.2
Cd	mg/L	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001
Cl	mg/L	5.0	6.3	2.2	11	16	6.0	1.4	2.1	0.5
Co	mg/L	0.02	0.4	0.1	0.1	2.9	0.6	0.004	0.004	0.004
Cr	mg/L	0.004	0.005	0.004	0.007	0.01	0.004	0.004	0.004	0.001
Cu	mg/L	0.05	0.2	0.3	0.3	1.2	1.2	0.004	0.003	0.003
F	mg/L	0.4	0.1	0.1	1.0	0.4	0.5	0.1	0.04	0.03
Fe	mg/L	0.003	0.01	0.04	0.003	0.06	0.2	0.001	0.001	0.001
Hg	mg/L	0.0002	0.0002	0.0002	0.001	0.001	0.001	0.0001	0.0001	0.0001
K [b]	mg/L	4.3	1.9	2.9	12	3.9	12	6.6	1.1	1.1
Mg	mg/L	10	6.6	5.4	42	29	24	3.8	1.7	0.3
Mn	mg/L	0.09	0.2	0.1	0.7	1.6	0.8	0.001	0.001	0.001
Na	mg/L	1.5	2.1	0.9	2.3	5.6	2.5	0.4	0.4	0.2
Ni	mg/L	0.01	0.01	0.01	0.02	0.03	0.01	0.01	0.01	0.007
P	mg/L	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.03
Pb	mg/L	0.003	0.003	0.002	0.006	0.007	0.006	0.002	0.002	0.002
SO_4 [b]	mg/L	14	13	11	68	20	33	3.8	5.3	1.8
Sb	mg/L	0.02	0.02	0.02	0.02	0.02	0.02	0.001	0.001	0.001
Se	mg/L	0.006	0.006	0.006	0.01	0.01	0.01	0.005	0.005	0.005
Tl	mg/L	0.03	0.03	0.03	0.03	0.03	0.03	0.001	0.001	0.001
Zn	mg/L	0.02	0.03	0.03	0.1	0.2	0.2	0.004	0.004	0.004

[a] TDS values are calculated.

[b] Sulfate and potassium concentrations may be elevated due to inclusion in charge balance.

[c] Arsenic detection limits ranged from 0.01 to 0.001 milligrams per liter. For samples with a detection limit of 0.01 milligrams per liter, a concentration of 0.005 milligrams per liter was assumed.

[d] Median pH value applied.

Shaded cells identify constituents below detectable limits in all sample(s) used to derive input water quality.

Non-detect concentrations assumed equal to the detection limit.

6.2.2.5 Input Water Qualities – Waste Rock Facility Seepage

Waste rock column leach test results were used to define a range of representative waste rock seepage water qualities. As discussed in Section 5.4.1.3, column leach test results typically showed the highest concentrations (as indicated by the highest conductivity) in pore volume 1 leachates. Leachate concentrations generally declined, and in many cases stabilized in the latter weeks of testing. The observed rapid decline in conductivity is often observed in column leach tests and represents the initial flush of readily-soluble components. Similar leaching behavior would be expected at the field scale. Therefore, both "first flush" and "long-term" seepage water qualities were determined.

First flush seepage qualities are considered representative of leaching during flushing of the first few pore volumes through the waste rock pile. Because addition of waste rock to the facility will be continuous during the operational mine life, "first flush" seepage will always be generated in a portion of the facility (i.e., the area where waste rock has been placed most recently). Long-term seepage qualities are representative of stable conditions following flushing with a few pore volumes, for instance after periods of prolonged rainfall or seepage through aged material.

For each of the three oxide waste rock classes, first flush water qualities were derived from the pore volume 1 column leachate results. For the SD and RSC waste rock classes, leachate results from the final five pore volumes were averaged to define a long-term water quality (i.e., pore volumes 7 to 11). Because leachate data for the RAT column are limited to five pore volumes, leachate results from the final two pore volumes were averaged to define a long-term water quality (i.e., pore volumes 4 and 5).

Application of laboratory leach test results to predict field scale conditions in the waste rock facility accounted for differences in: (1) solution to solid ratio; and, (2) waste rock surface area. Use of a surface area correction assumes that metal leachability is related to surface area such that as surface area increases, metal leaching increases proportionally. The surface areas of the waste rock column samples were estimated to range from 77 to 355 square meters per kilogram (Figure 5.1-1). The surface area (on a mass basis) of waste rock in the facility is expected to be much lower. Prediction of waste rock facility seepage qualities assumed that the surface area calculated for the bulk ore sample (0.14 square meters per kilogram) is representative of waste rock.

Column leachate concentrations were adjusted for field scale conditions following the steps listed below:

1. Column leachate concentrations (milligrams per liter) were converted to loading rates (milligrams per kilogram) based on the solution to solid ratio used in the column experiments.
2. Column loading rates (milligrams per kilogram) were converted to surface area rates (milligrams per square meter) assuming a surface area of 238 square meters per kilogram. This represents a weighted surface area for the waste rock columns based on the estimated proportions of the three oxide waste rock types within the facility.
3. Column surface area loading rates (milligrams per square meter) were multiplied by the total surface area of the waste rock facility (square meter) to determine metal load (milligram). The surface area of the waste rock facility was calculated assuming 142 million tonnes of waste rock with a surface area of 0.14 square meter per kilogram. To account for uncertainty in the estimation of waste rock surface area, total waste rock surface area was also estimated assuming a surface area of 1.4 square meter per kilogram (i.e., the estimated surface area was increased by an order of magnitude). These estimates are referred to as the “low surface area” and “high surface area” predictions, respectively. The use of an order of magnitude range in estimated waste rock surface area was based on professional judgment.
4. A seepage travel time of 60 days (i.e., two months) through the waste rock facility was assumed. The metal load calculated in Step 3 was divided by the average volume of seepage (liter) estimated to pass through the facility in a two-month period to yield a seepage concentration (milligrams per liter).

Steps 1 through 4 resulted in development of constant scaling factors to convert column leachate concentrations to seepage concentrations from the waste rock facility. For the low surface and high surface area scenarios, these scaling factors were 1.3 and 13, respectively. This implies that, in essence, for the low surface area simulations, predicted seepage concentrations are of the same order of magnitude as leachate concentrations in the columns, whereas for the high surface area simulations, predicted seepage concentrations are higher than column leachate concentrations by approximately one order of magnitude.

The range of waste rock seepage input water qualities for each waste rock class is shown in Table 6.2-4.

Table 6.2-4 Waste Rock Seepage Input Water Qualities

Time Period		First Flush						Long-Term					
Surface Area		Low Surface Area			High Surface Area			Low Surface Area			High Surface Area		
Oxide Waste Rock Class		SD	RSC	RAT	SD	RSC	RAT	SD	RSC	RAT	SD	RSC	RAT
pH	s.u.	7.7	7.9	7.9	7.7	7.9	7.9	8.1	8.8	8.2	8.1	8.8	8.2
alkalinity	mg/L as a CO_3	138	101	181	1,380	1,009	1,805	27	41	84	271	409	836
TDS [(a)]	mg/L	429	393	462	4,285	3,927	4,619	74	105	173	736	1,045	1,732
Ag	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01
Al	mg/L	0.3	0.001	0.001	3.4	0.01	0.01	0.02	0.02	0.001	0.2	0.2	0.01
As	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01
B	mg/L	0.1	0.1	0.1	1.3	1.3	1.3	0.1	0.1	0.1	1.3	1.3	1.3
Ba	mg/L	0.01	0.04	0.1	0.1	0.4	1.0	0.008	0.001	0.08	0.08	0.01	0.8
Be	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01
Br	mg/L	0.1	0.2	0.1	1.3	2.2	1.3	0.1	0.1	0.1	1.3	1.3	1.3
Ca	mg/L	33	27	22	334	274	219	3.5	1.8	4.8	35	18	48
Cd	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01
Cl	mg/L	48	72	21	478	717	212	6.6	6.6	6.6	66	66	66
Co	mg/L	0.01	0.03	0.2	0.1	0.3	2.4	0.004	0.002	0.001	0.04	0.02	0.01
Cr	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.002	0.01	0.01	0.02
Cu	mg/L	0.2	0.09	0.7	2.3	0.9	7.5	0.01	0.006	0.02	0.1	0.06	0.2
F	mg/L	1.5	0.4	0.9	15	4.0	9.3	0.3	0.3	0.3	2.7	2.7	3.3
Fe	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01
Hg	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01
K [(b)]	mg/L	26	48	25	261	484	248	19	38	43	188	383	426
Li	mg/L	0.1	0.09	0.09	1.3	0.9	0.9	0.008	0.003	0.005	0.08	0.03	0.05
Mg	mg/L	37	24	44	366	241	439	2.7	1.1	8.2	27	11	82
Mn	mg/L	0.01	0.02	0.3	0.1	0.2	3.3	0.002	0.001	0.009	0.02	0.01	0.09
Mo	mg/L	0.03	0.009	0.03	0.3	0.09	0.3	0.002	0.001	0.005	0.02	0.01	0.05
Na	mg/L	18	22	23	177	222	226	0.1	0.04	0.3	1.2	0.4	3.1
Ni	mg/L	0.009	0.007	0.02	0.09	0.07	0.2	0.005	0.001	0.001	0.05	0.01	0.01
P	mg/L	0.1	0.1	0.1	1.3	1.3	1.3	0.1	0.1	0.1	1.3	1.3	1.3
Pb	mg/L	0.07	0.001	0.003	0.7	0.01	0.03	0.002	0.001	0.003	0.02	0.01	0.03
Sb	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01
Se	mg/L	0.01	0.01	0.01	0.1	0.1	0.1	0.01	0.01	0.01	0.1	0.1	0.1
Si	mg/L	2.3	3.1	5.7	23	31	57	1.6	0.3	2.8	16	2.6	28
Sn	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01
SO_4 [(b)]	mg/L	96	73	102	960	730	1,020	6.9	6.6	6.6	69	66	66
Sr	mg/L	0.2	0.5	0.1	1.9	5.0	1.4	0.02	0.01	0.04	0.2	0.1	0.4
Tl	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01
U	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01
V	mg/L	0.001	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.01
Zn	mg/L	0.03	0.001	0.001	0.3	0.01	0.01	0.1	0.001	0.001	1.3	0.01	0.01

[(a)] TDS values are calculated.

[(b)] Sulfate and potassium concentrations may be elevated due to inclusion in charge balance.

Shaded cells identify constituents below detectable limits in all samples used to derive input water quality.

Non-detect concentrations assumed equal to the detection limit.

6.2.2.6 Summary of Model Simulations

Tables 6.2-5 and 6.2-6 list the mass balance (MB) model simulations conducted to predict waste rock runoff and seepage quality, respectively. In all simulations, oxide waste rock qualities were mixed in the following proportions: SD (68 percent), RSC (5 percent) and RAT (27 percent) to determine a resultant water quality. These simulations were conducted to capture the expected range in waste rock runoff and seepage water quality during operations. To assess the effect of geochemical controls (GC) such as mineral precipitation, geochemical modeling was conducted for all scenarios.

Table 6.2-5 Waste Rock Runoff Model Simulations

Simulation	Input Water Quality Derivation	Model Type	
	Metal Loading Rate (determined from SPLP tests)	Mass Balance (MB)	Geochemical Controls (GC)
WR-1A	average	x	x
WR-1B	maximum	x	x
WR-1C	minimum	x	x

Table 6.2-6 Waste Rock Seepage Model Simulations

Simulation	Input Water Quality Derivation		Model Type	
	Time Period	Waste Rock Facility Surface Area	Mass Balance (MB)	Geochemical Controls (GC)
WR-2A	first flush	low	x	x
WR-2B	first flush	high	x	x
WR-2C	long-term	low	x	x
WR-2D	long-term	high	x	x

6.2.2.7 Nitrogen Loading

Nitrogen is predicted to be present in waste rock seepage and runoff due to flushing of residuals from blasting. ANFO will be used as the principal blasting agent (Section A4). The basic ANFO mixture of 94 percent ammonium nitrate and six percent fuel oil contains 33 percent (by weight) nitrogen. Nitrogen is present as ammonium (NH_4^+) and nitrate (NO_3^-) ions, which are readily soluble in water (Forsyth et al. 1995). During operations, Phelps Dodge estimates that residual ANFO concentrations in waste rock will be two percent of ANFO use

(Baloo 2006). ANFO wastage is due to factors such as spillage and undetonated explosives (i.e., misfires).

Predictions of waste rock runoff and seepage nitrogen concentrations were based on the final waste rock facility dimensions and the following assumptions:

- Ammonia and nitrate concentrations in waste rock seepage and runoff will be the same.
- The average consumption of ANFO for the first 13 years of production will be 2,350 tonnes per year (Baloo 2006). Approximately two percent of ANFO use will report to the waste rock facility as blasting residual (Baloo 2006).
- Nitrate and ammonia present in blasting residual will be readily soluble.
- Average annual runoff and seepage (combined) from the waste rock facility will be 518 millimeters (see Table 6.2-2).
- Nitrogen transport was assumed to be conservative (i.e., no attenuation due to chemical reactions).

The average annual waste rock seepage/runoff nitrogen concentration (i.e., nitrate and ammonia) was calculated assuming 10 percent of the annual nitrogen load is dissolved in the average annual volume of seepage and runoff combined. The assumption that 10 percent of the total nitrogen load is solubilized is based on experience at other mine sites where ANFO is used as a blasting agent and nitrogen concentrations on the order of 10s of mg/L have been observed.

6.2.3 Waste Rock Facility Water Qualities

6.2.3.1 Operational Waste Rock Runoff

Waste rock runoff model results are shown in Table 6.2-7. Results for each model simulation are shown with and without the influence of geochemical controls (i.e., precipitation of credible mineral phases and equilibrium with atmospheric carbon dioxide). An Eh of 400 millivolts, representative of oxidizing conditions, was assumed for waste rock runoff. Minerals predicted to precipitate are identified at the bottom of the table. The final two columns of the table summarize the overall predicted range in waste rock runoff water quality during operations.

For a number of constituents, leachate concentrations were below detectable limits in all SPLP leachates. These constituents are identified in the column labeled “non-detects”. Concentrations below detectable limits were assumed

equal to the detection limit in all calculations, and predicted concentrations for these constituents (i.e., Ag, Cd, P, Sb, Se and Tl), therefore likely are biased high.

The pH of waste rock runoff is predicted to range from approximately six to nine. Dissolved copper and cobalt concentrations are predicted to range from a microgram per liter up to hundreds of microgram per liter levels. Trace metals which are predicted to occur at microgram per liter to tens of micrograms per liter concentrations include: Ag, As, Be, Cr, Fe, Hg, Ni and Pb. The following trace metals are also predicted to occur within this range; however, predictions are based on SPLP results that were below detectable limits: Cd, Sb, Se and Tl. Zinc concentrations up to a hundred micrograms per liter are predicted. Without geochemical controls, manganese concentrations up to almost milligram per liter levels are predicted. Precipitation of rhodochrosite [$MnCO_3$] may limit manganese concentrations to a few hundreds of micrograms per liter.

Table 6.2-7 Waste Rock Runoff Model Results

Metal Loading Rate		Average		Maximum		Minimum		Non-Detects [e]	Detection Limit [f]	Predicted Range	
Geochemical Controls		No Control	Control	No Control	Control	No Control	Control		mg/L	Max.	Min.
pH	s.u.	8.5	8.3	6.4	8.3	9.4	8.0			9.4	6.4
alkalinity [g]	mg/L as $CaCO_3$	58	58	233	53	23	23			58	23
TDS [d]	mg/L	116	115	280	65	201	43			280	43
Ag	mg/L	0.003	0.003	0.003	0.003	0.001	0.001	X	0.001 or 0.003	0.003	0.001
Al	mg/L	0.1	0.1	0.3	0.3	0.002	0.002		0.001 or 0.02	0.3	0.002
As	mg/L	0.003	0.003	0.008	0.008	<0.001	<0.001		0.001 or 0.01	0.008	<0.001
Ba	mg/L	0.05	0.05	0.3	0.05	0.002	0.002		0.002 or 0.007	0.3	0.002
Be	mg/L	0.001	0.001	0.001	0.001	<0.001	<0.001		0.001	0.001	<0.001
Ca	mg/L	14	14	53	18	4.1	4.1			53	4.1
Cd	mg/L	0.002	0.002	0.002	0.002	<0.001	<0.001	X	0.001 or 0.002	0.002	<0.001
Cl	mg/L	4.3	4.3	10	10	1.2	1.2		5.0 [h]	10	1.2
Co [c]	mg/L	0.06	0.06	0.4	0.4	0.004	0.004		0.004	0.4	0.004
Cr	mg/L	0.004	0.004	0.007	0.007	0.003	0.003		0.001 or 0.004	0.007	0.003
Cu [c]	mg/L	0.1	0.02	0.6	0.02	0.004	0.004		0.003	0.6	0.004
F	mg/L	0.3	0.3	0.8	0.8	0.1	0.1		0.2 [h]	0.8	0.1
Fe	mg/L	0.01	<0.001	0.06	<0.001	<0.001	<0.001		0.001 or 0.003	0.06	<0.001
Hg	mg/L	<0.001	<0.001	0.001	<0.001	<0.001	<0.001		0.001 or 0.0001	0.001	<0.001
K [b]	mg/L	3.8	3.8	11	11	4.8	4.8		0.8	11	3.8

Table 6.2-7 Waste Rock Runoff Model Results (continued)

Metal Loading Rate		Average		Maximum		Minimum		Non-Detects [e]	Detection Limit [f]	Predicted Range	
Geochemical Controls		No Control	Control	No Control	Control	No Control	Control		mg/L	Max.	Min.
Mg [c]	mg/L	8.8	8.8	36	15	2.8	2.8			36	2.8
Mn	mg/L	0.1	0.1	0.8	0.3	<0.001	<0.001		0.001	0.8	<0.001
Na	mg/L	1.4	1.4	2.5	2.5	0.3	0.3			2.5	0.3
Ni	mg/L	0.01	0.01	0.02	0.02	0.009	0.009		0.01	0.02	0.009
P	mg/L	0.3	0.3	0.3	0.3	0.2	0.2	X	0.03 or 0.2 or 0.3	0.3	0.2
Pb	mg/L	0.003	0.003	0.006	0.006	0.002	0.002		0.002	0.006	0.002
SO_4 [b]	mg/L	13	13	56	56	3.3	3.3		5.0 [h]	56	3.3
Sb	mg/L	0.02	0.02	0.02	0.02	0.001	0.001	X	0.001 or 0.02	0.02	0.001
Se	mg/L	0.006	0.006	0.01	0.01	0.005	0.005	X	0.005 or 0.01	0.01	0.005
Tl	mg/L	0.03	0.03	0.03	0.03	0.001	0.001	X	0.001 or 0.03	0.03	0.001
Zn	mg/L	0.02	0.02	0.1	0.1	0.004	0.004		0.004	0.1	0.004
Minerals Predicted to Precipitate [a]											
barite [$BaSO_4$]					X						
dolomite [$CaMg(CO_3)_2$]					X						
ferrihydrite [$Fe(OH)_3$]			X		X						
malachite [$Cu_2(OH)_2CO_3$]			X		X						
rhodochrosite [$MnCO_3$]					X						

(a) "X" indicates that the mineral is predicted to precipitate. In some cases, mineral precipitation may be too small to result in a reported reduction in constituent concentrations (i.e., reduction may be less then the number of significant figures reported in the table).

(b) Sulfate and potassium concentrations may be elevated due to inclusion in charge balance.

(c) See Section 6.1.2 for a discussion of predicted copper, cobalt and magnesium concentrations for pH values between 6 and 9.

(d) TDS values are calculated.

(e) Constituent not detected in any SPLP leachates used in the prediction of runoff quality.

(f) Detection limit shown for all constituents reporting at least one leachate result below detectable concentrations.

(g) Minimum and maximum alkalinity values determined from the control results only.

(h) Detection limit for Golder samples only.

6.2.3.2 Operational Waste Rock Seepage

Waste rock seepage model results are shown in Table 6.2-8. Results for each model simulation are shown with and without the influence of geochemical controls (i.e., precipitation of credible mineral phases and equilibrium with atmospheric carbon dioxide). An Eh of 400 millivolts was assumed for waste rock seepage. Minerals predicted to precipitate are identified at the bottom of the table. The final two columns of the table summarize the predicted range in waste rock seepage water quality during operations.

For a number of constituents, leachate concentrations were below detectable limits in all column leachates used in the estimation of seepage qualities. These constituents are identified in the column labeled "non-detects". For these constituents (i.e., Ag, B, Cd, Fe, P, Sb, Se, Tl and V), predicted concentrations likely are biased high because concentrations below detectable limits were assumed equal to the detection limit.

The three waste rock columns consistently yielded leachates with circum-neutral to alkaline pH values (Figure 5.4-25). Waste rock seepage modeling indicated a range of pH values from 7.8 to 8.9. Because column results are available for only three samples and because SPLP leach tests yielded a wider range of pH values (6.4 to 8.9), waste rock seepage pH in reality may demonstrate a greater range than predicted by the model.

Based on the results of waste rock seepage modeling, dissolved copper and cobalt concentrations are predicted to range from microgram per liter to milligram per liter levels. These levels are predicted for seepage with pH values ranging from 7.8 to 8.9. If seepage pH values were to decline below 7.8, higher cobalt and copper seepage concentrations may occur than those shown in Table 6.2-8. It is expected that travel time through the waste rock facility (i.e., one to three months) will be long enough to establish equilibrium with respect to malachite and cobalt bearing mineral phases. As discussed in Section 6.1.2, at pH values of 6, seepage copper and cobalt concentrations on the order of a few milligrams per liter and 10s of milligram per liter, respectively, are possible.

Trace metals which are predicted to occur at microgram per liter to tens of microgram per liter concentrations in waste rock seepage include: As, Be, Cr, Hg, Sn and U. The following trace metals are also predicted to occur within this range; however, predictions are based on column results that were below the detectable limits: Ag, Cd, Fe, Sb, Tl and V. For a few trace metals, concentrations up to 100s of microgram per liter are predicted (e.g., Li, Mn, Mo, Ni, Pb, Se [based on detection limit values] and Zn).

Table 6.2-8 Waste Rock Seepage Model Results

Time Period		First Flush				Long-Term				Non-Detects [e]	Detection Limit [f]	Predicted Range	
Waste Rock Surface Area		Low Surface Area		High Surface Area		Low Surface Area		High Surface Area				Max.	Min.
Geochemical Controls		No Control	Control	No Control	Control	No Control	Control	No Control	Control				
pH	s.u.	7.8	8.3	7.8	8.1	8.2	8.2	8.2	8.9			8.9	7.8
alkalinity [g]	mg/L as $CaCO_3$	148	54	1,476	62	43	43	430	220			220	43
TDS [d]	mg/L	436	293	4,357	2,203	102	102	1,021	701			4,357	102
Ag	mg/L	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01	X	0.001	0.01	0.001
Al	mg/L	0.2	0.2	2.3	2.1	0.02	0.02	0.2	0.2		0.001	2.3	0.02
As	mg/L	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01		0.001 [h]	0.01	0.001
B	mg/L	0.1	0.1	1.3	1.3	0.1	0.1	1.3	1.3	X	0.1	1.3	0.1
Ba	mg/L	0.04	0.03	0.4	0.01	0.03	0.03	0.3	0.05		0.001	0.4	0.01
Be	mg/L	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01		0.001	0.01	0.001
Br	mg/L	0.1	0.1	1.4	1.4	0.1	0.1	1.3	1.3		0.1	1.4	0.1
Ca	mg/L	30	11	300	18	3.8	3.8	38	0.2			300	0.2
Cd	mg/L	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.005	X	0.001	0.01	0.001
Cl	mg/L	42	42	418	418	6.6	6.6	66	66		5.0	418	6.6
Co [c]	mg/L	0.08	0.08	0.8	0.8	0.003	0.003	0.03	0.03		0.001	0.8	0.003
Cr	mg/L	0.001	0.001	0.01	0.01	0.002	0.002	0.02	0.02		0.001	0.02	0.001
Cu [c]	mg/L	0.4	0.02	3.6	0.02	0.01	0.01	0.1	0.02			3.6	0.01
F	mg/L	1.3	1.3	13	13	0.3	0.3	2.8	2.8		0.2	13	0.3
Fe	mg/L	0.001	<0.001	0.01	<0.001	0.001	<0.001	0.01	<0.001	X	0.001	0.01	<0.001
Hg	mg/L	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01		0.001 [h]	0.01	0.001
K [b]	mg/L	27	27	269	269	26	26	262	262			269	26
Li	mg/L	0.1	0.1	1.2	1.2	0.007	0.007	0.07	0.07			1.2	0.01
Mg [c]	mg/L	38	27	380	209	4.1	4.1	41	13			380	4.1
Mn	mg/L	0.1	0.1	1.0	1.0	0.004	0.004	0.04	0.02		0.001	1.0	0.004
Mo	mg/L	0.03	0.03	0.3	0.3	0.003	0.003	0.03	0.03		0.001	0.3	0.003

Table 6.2-8 Waste Rock Seepage Model Results (continued)

Time Period		First Flush				Long-Term				Non-Detects [e]	Detection Limit [f]	Predicted Range	
Waste Rock Surface Area		Low Surface Area		High Surface Area		Low Surface Area		High Surface Area				Max.	Min.
Geochemical Controls		No Control	Control	No Control	Control	No Control	Control	No Control	Control				
Na	mg/L	19	19	192	192	0.2	0.2	1.7	1.7			192	0.2
Ni	mg/L	0.01	0.01	0.1	0.1	0.004	0.004	0.04	0.04		0.001	0.1	0.004
P	mg/L	0.1	0.1	1.3	1.3	0.1	0.1	1.3	1.3	X	0.1	1.3	0.1
Pb	mg/L	0.05	0.05	0.5	0.08	0.002	0.002	0.02	0.02		0.001	0.5	0.002
Sb	mg/L	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01	X	0.001	0.01	0.001
Se	mg/L	0.01	0.01	0.1	0.1	0.01	0.01	0.1	0.1	X	0.01	0.1	0.01
Si	mg/L	3.3	3.3	33	33	1.8	1.8	18	18			33	1.8
Sn	mg/L	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01		0.001 [h]	0.01	0.001
SO_4 [b]	mg/L	96	96	965	964	6.8	6.8	68	68		5.0	965	6.8
Sr	mg/L	0.2	0.2	2.0	2.0	0.02	0.02	0.2	0.2			2.0	0.02
Tl	mg/L	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01	X	0.001	0.01	0.001
U	mg/L	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01		0.001 [h]	0.01	0.001
V	mg/L	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01	X	0.001	0.01	0.001
Zn	mg/L	0.02	0.02	0.2	0.2	0.09	0.09	0.9	0.6		0.001	0.9	0.02

Table 6.2-8 Waste Rock Seepage Model Results (continued)

Time Period	First Flush				Long-Term				Non-Detects [e]	Detection Limit [f]	Predicted Range	
Waste Rock Surface Area	Low Surface Area		High Surface Area		Low Surface Area		High Surface Area				Max.	Min.
Geochemical Controls	No Control	Control	No Control	Control	No Control	Control	No Control	Control				
Minerals Predicted to Precipitate [a]												
$Al_4(OH)_{10}SO_4$				X								
barite [$BaSO_4$]		X		X				X				
cerrusite [$PbCO_3$]				X								
dolomite [$CaMg(CO_3)_2$]		X		X				X				
ferrihydrite [$Fe(OH)_3$]		X		X		X		X				
malachite [$Cu_2(OH)_2CO_3$]		X		X				X				
manganite [MnOOH]				X				X				
magnesite [$MgCO_3$]								X				
otavite [$CdCO_3$]								X				
smithsonite [$ZnCO_3$]								X				

[a] "X" indicates that the mineral is predicted to precipitate. In some cases, mineral precipitation may be too small to result in a reported reduction in constituent concentrations (i.e., reduction may be less then the number of significant figures reported in the table).

[b] Sulfate and potassium concentrations may be elevated due to inclusion in charge balance.

[c] See Section 6.1.2 for a discussion of predicted copper, cobalt and magnesium concentrations for pH values between 6 and 9.

[d] TDS values are calculated.

[e] Constituent not detected in any column leachates used in the prediction of seepage quality.

[f] Detection limit shown for all constituents reporting at least one leachate result below detectable concentrations.

[g] Minimum and maximum alkalinity values determined from the control results only.

[h] All samples at or below the detection limit.

6.2.3.3 Waste Rock Seepage and Runoff Nitrogen

Ammonia and nitrogen concentrations in waste rock seepage and runoff are predicted to be in the tens of milligrams per liter. Assuming that two percent of the annual ANFO use of 2,350 tonnes per year reports to the waste rock facility and that, on an annual basis, 10 percent of this load is solubilized in average runoff and seepage from the waste rock facility, average annual ammonia and nitrate concentrations of 13 milligrams per liter-N are predicted.

6.2.3.4 Long-Term Waste Rock Seepage and Runoff

In the absence of mitigating measures (i.e., placement of a cover), long-term waste rock seepage and runoff water qualities are predicted to be within the ranges predicted for operations. Similarities between operational and long-term runoff and seepage quality are expected because of an absence of reactive sulfides that could cause generation of acidic conditions over time. Instead, pH conditions are anticipated to remain approximately constant. For waste rock seepage, predicted long-term water qualities (predicted using data from the latter stages of column leach testing) are likely more representative of long-term conditions than first flush predictions (predicted using data from the early-time early time column leach testing). The column leach test results typically demonstrated a general decline in conductivity and constituent concentrations during the first few pore volumes. Similar concentration trends over time are predicted for waste rock seepage.

6.2.3.5 Assumptions

Prediction of waste rock seepage and runoff water quality assumed that the oxide waste rock is unreactive with respect to sulfide oxidation. ABA and NAG testing of oxide waste rock samples indicated no potential to generate acidity (see Section 5.3.1). The evaluation of waste rock water qualities therefore did not need to account for any transient effects resulting from sulfide oxidation (in particular, generation of acidic conditions and oxidation products) within the waste rock facility. Geochemical characterization to date has focused on samples from the oxide ore zone. If operational monitoring indicates the presence of sulfidic waste, the predictions of waste rock seepage and runoff would need to be re-evaluated.

6.3 ORE STOCKPILES

6.3.1 Introduction

Ore will be stockpiled in long-term or short-term facilities prior to processing. Adjacent to the waste rock facility, there will be two long-term low grade ore stockpiles. Material is expected to be stockpiled in this area for at least twenty years. Adjacent to the plant site, there will be up to six short-term high-grade ROM ore stockpiles to allow blending of ore, each with varying copper and cobalt concentrations. This section presents the approach and results for the prediction of ore stockpile runoff and seepage quality during operations.

The quality of ore stockpile seepage and runoff will be a function of the following:

- The composition of the ore stockpiles.
- The reactivity (or stability) of the ore and the interaction between the stockpiled ore and recharge (i.e., the solution to solids ratio and amount of contact time between ore stockpile runoff/seepage and ore).

Figure 6.1-4 shows the estimated mass of ore that will be mined between years 2007 and 2027 for all three ore bodies. The cumulative amount of ore processed on an annual basis is also shown. This ore will be placed in the short-term ROM ore stockpiles. The tonnage of the long-term ore stockpiles is expected to peak at approximately 55 million tonnes in year 2020.

Estimated average copper and cobalt grades for ore to be placed in the short-term ROM ore stockpiles are shown in Figure 6.3-1. Between 2007 and 2020, the average copper content of the ore is expected to range from approximately 4 weight percent to 4.7 weight percent. After year 2020, the average copper content of the ore is expected to decrease. The cobalt content of the ore is expected to remain relatively stable at 0.2 to 0.5 weight percent. Estimated average copper and cobalt grades for ore to be placed in the long-term ore stockpiles are shown in Figure 6.3-2. The copper and cobalt contents of the ore in the long-term stockpile are estimated at approximately 0.7 and 0.3 weight percent, respectively.

Prediction of ore stockpile seepage and runoff quality utilized the results of the ore stockpile water balance to define the physical system. Results from the ore geochemical characterization program were applied to predict metal leaching following weathering of ore placed on the long-term stockpiles. Leach test results for the artisanal samples were used to predict metal leaching from the short-term ROM ore stockpiles. It should be noted that use of the artisanal

samples likely results in conservative (i.e., likely worst case) predictions of ROM ore stockpile seepage and runoff for the following reasons. Firstly, the artisanal samples reported higher copper and cobalt concentrations than the average mine grade (Table 5.2-3). Secondly, the artisanal samples, collected from ground surface, are representative of weathered oxide ore material, which probably has resulted in depletion of their neutralization potential. As shown in Table 5.4-3, these samples reported lower SPLP leachate pH values than the bulk upper ore sample (Table 5.4-9). The artisanal material samples are likely most representative of the ore that will be mined in the very early stages of the mine life. In general, the approach for the prediction of ore stockpile water qualities was the same as that applied for the waste rock. A brief description of the approach, with references to the approach to waste rock predictions as appropriate, follows.

6.3.2 Model Approach and Methodology

6.3.2.1 Overview

The general modeling sequence followed the steps listed below:

1. ***Define ore stockpile composition***. The physical properties of the long-term and short-term ore stockpiles (i.e., height, surface area and ore tonnage) were compiled. The West and East long-term stockpiles were modeled as a single pile (i.e., tonnages and footprint surface areas were combined).
2. ***Define input water qualities***. Ore stockpile seepage and runoff chemistries were derived from the column leach test and SPLP leach test results, respectively. Consistent with the waste rock modeling approach, the water quality prediction effort made use of both mass loading and surface area loading approaches. A range of input water qualities was defined for both ore stockpile runoff and seepage.
3. ***Consideration of geochemical controls***. The chemical speciation of ore stockpile seepage/runoff was determined with PHREEQC. Supersaturated mineral phases were identified and evaluated for their likelihood to precipitate from the solution. The effect of equilibrium with appropriate atmospheric gases (i.e., carbon dioxide) was evaluated. After equilibration with the selected solid phases and carbon dioxide, the solution composition was determined anew.
4. ***Nitrogen loading***. Consistent with the approach to nitrogen leaching for waste rock, prediction of nitrogen concentrations in ore stockpile seepage and runoff assumed a source from residual products of blasting agents (i.e., ANFO).

Each of these steps is described in more detail in the following sections.

6.3.2.2 Ore Stockpile Composition

The dimensions of the ore stockpiles, as presented in the ESIA (Section A4), are shown in Table 3.2-1.

The water balances for the long-term and short-term ROM stockpiles are shown in Table 6.3-1. For the long-term stockpiles, assuming a MAP of 1,200 millimeters, approximately 10 percent of MAP will report as runoff and 34 percent will report as seepage at the toe or base of the stockpile. This water balance is representative of a stockpile with a height of approximately 30 meters. The estimated travel time for seepage through the long-term stockpile is a few months. For the ROM short-term stockpiles, assuming a MAP of 1,200 millimeters, approximately 12 percent of MAP will report as runoff and 32 percent will report as seepage at the toe or base of the stockpile. This water balance is representative of a stockpile with a height of approximately 10 meters. The estimated travel time for seepage through the ROM stockpile is a few days (Feasibility Study – MinProc 2007).

Table 6.3-1 Long-Term and Short-Term ROM Ore Stockpile Water Balances

	Long-Term		Short-Term ROM	
	Depth (mm)	Percentage of MAP (%)	Depth (mm)	Percentage of MAP (%)
mean annual precipitation (MAP)	1,200		1,200	
runoff	119	10	146	12
Seepage (toe seepage and seepage to groundwater)	408	34	379	32

6.3.2.3 Input Water Qualities – Ore Stockpile Runoff

Short-term SPLP leach test results were used to define a range of representative ore runoff water qualities. SPLP leach test results for the upper bulk ore sample were presented in Table 5.4-9. These results were used to estimate runoff from the long-term ore stockpiles. Due to their elevated copper and cobalt contents, SPLP leach test results for the artisanal material samples were used to define a range of representative short-term ROM ore stockpile runoff qualities.

The approach to estimation of ore stockpile runoff quality was the same as that applied for waste rock. SPLP leachate concentrations (in milligrams per liter) were assumed to be representative of runoff concentrations. To predict runoff quality from the long-term ore stockpile, average and maximum SPLP results from the upper bulk ore sample were determined. To predict runoff quality from the ROM ore stockpile, SPLP results from each of the two artisanal material samples were used. Long-term and short-term ROM ore stockpile runoff input water qualities are shown in Tables 6.3-2 and 6.3-3.

Table 6.3-2 Long-Term Ore Stockpile Runoff Input Water Qualities

Loading Rate		Average	Maximum
pH	s.u.	6.7	6.6
TDS [(a)]	mg/L	13	18
alkalinity [(c)]	mg/L as $CaCO_3$	1.1	2.1
Ag	mg/L	0.00005	0.00005
Al	mg/L	0.007	0.01
As	mg/L	0.0005	0.0007
B	mg/L	0.02	0.02
Ba	mg/L	0.0004	0.0006
Be	mg/L	0.0002	0.0002
Ca	mg/L	0.3	0.5
Cd	mg/L	0.00004	0.00004
Co	mg/L	0.08	0.2
Cr	mg/L	0.0003	0.0003
Cu	mg/L	0.1	0.2
Fe	mg/L	0.01	0.01
Hg	mg/L	0.00002	0.00002
K	mg/L	2.4	2.5
Li	mg/L	0.007	0.008
Mg	mg/L	0.1	0.2
Mn	mg/L	0.002	0.003
Mo	mg/L	0.0004	0.0007
Na	mg/L	0.9	1.6
Ni	mg/L	0.0004	0.0006
P	mg/L	0.03	0.03
Pb	mg/L	0.0002	0.0002
Sb	mg/L	0.0003	0.0003
Se	mg/L	0.0002	0.0002
Si	mg/L	2.3	2.5
Sn	mg/L	0.0003	0.0003
SO_4 [(b)]	mg/L	5.3	7.2
Sr	mg/L	0.0008	0.001
Tl	mg/L	0.00002	0.00002
U	mg/L	0.0001	0.0001
V	mg/L	0.0002	0.0002
Zn	mg/L	0.003	0.005

(a) TDS values are calculated.

(b) Sulfate concentrations may be elevated due to inclusion in charge balance.

(c) Alkalinity not included in leachate analysis. Initial alkalinity values estimated from calcium concentration.

Anions not included in analysis of SPLP leachates. Sulfate concentrations determined using a charge balance approach.

Shaded cells identify constituents below detectable limits in all samples used to derive input water quality. Non-detect concentrations assumed equal to the detection limit.

Table 6.3-3 Short-Term ROM Ore Stockpile Runoff Input Water Qualities

ROM Loading Rate		Artisanal 1	Artisanal 2
pH	s.u.	5.8	5.6
TDS [(a)]	mg/L	113	86
alkalinity[(c)]	mg/L as $CaCO_3$	12	8.6
Ag	mg/L	0.001	0.001
Al	mg/L	0.02	0.001
As	mg/L	0.001	0.001
B	mg/L	0.1	0.1
Ba	mg/L	0.02	0.01
Be	mg/L	0.001	0.001
Ca	mg/L	2.8	2.1
Cd	mg/L	0.001	0.001
Cl	mg/L	5.0	5.0
Co	mg/L	2.9	2.2
Cr	mg/L	0.001	0.001
Cu	mg/L	28	22
F	mg/L	0.2	0.2
Fe	mg/L	0.001	0.001
Hg	mg/L	0.001	0.001
K	mg/L	1.2	1.4
Li	mg/L	0.01	0.009
Mg	mg/L	2.3	1.7
Mn	mg/L	0.2	0.06
Mo	mg/L	0.001	0.001
Na	mg/L	1.3	1.3
Ni	mg/L	0.02	0.02
P	mg/L	0.1	0.1
Pb	mg/L	0.005	0.005
Sb	mg/L	0.001	0.001
Se	mg/L	0.01	0.01
Si	mg/L	4.8	2.5
Sn	mg/L	0.002	0.001
SO_4 [(b)]	mg/L	49	37
Sr	mg/L	0.02	0.01
Tl	mg/L	0.001	0.001
U	mg/L	0.001	0.001
V	mg/L	0.001	0.001
Zn	mg/L	0.2	0.2

(a) TDS values are calculated.

(b) Sulfate concentrations may be elevated due to inclusion in charge balance.

(c) Alkalinity not included in leachate analysis. Initial alkalinity values estimated from calcium concentration.

Shaded cells identify constituents below detectable limits in all samples used to derive input water quality. Non-detect concentrations assumed equal to the detection limit.

6.3.2.4 Input Water Qualities – Ore Stockpile Seepage

The results from the upper bulk ore column leach test were used to define a range of representative long-term ore stockpile seepage water qualities. The approach to estimation of ore seepage water qualities was the same as that applied for waste rock. A first-flush water quality was derived from the pore volume 1 column leachate results. Leachate results from the last five pore volumes (i.e., pore volumes 17 to 21) were averaged to define long-term seepage quality.

Application of laboratory leach test results to predict field scale conditions accounted for differences in: (1) solution to solid ratio; and (2) waste rock surface area. The surface area of the bulk upper ore sample was estimated at 9 square meters per kilogram (Figure 5.1-1). The surface area (on a mass basis) of the ore stockpiles is expected to be closer to that of the bulk ore sample (0.14 square meters per kilogram). Column leachate concentrations were adjusted for field scale conditions as follows:

1. Column leachate concentrations (milligrams per liter) were converted to loading rates (milligrams per kilogram) based on the column test solution to solid ratio (this calculation considered the higher solution to solid ratio applied in pore volume 1 than subsequent pore volumes).
2. Column loading rates (milligrams per kilogram) were converted to surface area rates (milligrams per meters squared) assuming a surface area of nine square meters per kilogram.
3. Column surface area loading rates (milligrams per square meter) were multiplied by the total surface area of the long-term ore stockpile (square meters) (East and West stockpiles combined) to determine metal load (milligrams). This calculation was performed using both the short-term stockpile and low-grade ore stockpile tonnages. The surface areas of the stockpiles were calculated assuming a surface area of 0.14 square meters per kilogram. To account for uncertainty in the estimation of ore surface area, total ore stockpile surface area was also estimated assuming a surface area of 1.4 square meters per kilogram (i.e., the estimated surface area was increased by an order of magnitude). These estimates are referred to as the “low surface area” and “high surface area” predictions, respectively.
4. A seepage travel time of two months (i.e., 60 days) within the long-term stockpile was assumed. The metal loads calculated in Step 3 were divided by the average volume of seepage (liters) estimated to pass through the stockpile in two months to yield a seepage concentration.

Steps 1 through 4 resulted in application of scaling factors of 6 (low surface area) and 64 (high surface area) to convert first-flush column leachate concentrations

to ore stockpile seepage concentrations. Steps 1 through 4 resulted in application of scaling factors of 4 (low surface area) and 39 (high surface area) to convert long-term column leachate concentrations to ore stockpile seepage concentrations. This implies that, in essence, for the low surface area simulations, predicted seepage concentrations are four to six times (approximately one order of magnitude) higher than leachate concentrations in the columns, whereas for the high surface area simulations, predicted seepage concentrations are higher than column leachate concentrations by slightly less than two orders of magnitude.

The range of ore stockpile seepage input water qualities is shown in Table 6.3-4.

Table 6.3-4 Ore Stockpile Seepage Input Water Qualities

Time Period		First Flush		Long-Term	
Surface Area		Low Surface Area	High Surface Area	Low Surface Area	High Surface Area
pH	s.u.	6.2	6.2	6.3	6.3
alkalinity	mg/L as $CaCO_3$	19	185	12	122
TDS [(a)]	mg/L	98	984	38	380
Ag	mg/L	0.0003	0.003	0.0002	0.002
Al	mg/L	0.08	0.8	0.03	0.3
As	mg/L	0.003	0.03	0.001	0.01
B	mg/L	0.4	3.9	0.1	1.0
Ba	mg/L	0.009	0.09	0.003	0.03
Be	mg/L	0.001	0.01	0.0008	0.008
Ca	mg/L	1.7	17	0.6	6.3
Cd	mg/L	0.0003	0.003	0.0002	0.002
Cl	mg/L	12	122	0.9	8.6
Co	mg/L	1.4	14	0.4	4.0
Cr	mg/L	0.003	0.03	0.0008	0.008
Cu	mg/L	2.4	24	0.9	9.5
F	mg/L	0.3	3.2	0.2	2.0
Fe	mg/L	0.06	0.6	0.04	0.4
Hg	mg/L	0.0001	0.001	0.0001	0.0008
K [(b)]	mg/L	21	208	8.7	87
Li	mg/L	0.1	1.2	0.01	0.1
Mg	mg/L	2.2	22	0.5	5.2
Mn	mg/L	0.03	0.3	0.01	0.1
Mo	mg/L	0.005	0.05	0.002	0.02
Na	mg/L	4.3	43	0.4	3.8

Table 6.3-4 Ore Stockpile Seepage Input Water Qualities (continued)

Time Period		First Flush		Long-Term	
Surface Area		Low Surface Area	High Surface Area	Low Surface Area	High Surface Area
Ni	mg/L	0.007	0.07	0.002	0.02
P	mg/L	0.2	1.9	0.1	1.4
Pb	mg/L	0.001	0.01	0.0008	0.008
Sb	mg/L	0.001	0.01	0.0008	0.008
Se	mg/L	0.001	0.01	0.0008	0.008
Si	mg/L	10	104	6.4	64
Sn	mg/L	0.001	0.01	0.0008	0.008
SO_4	mg/L	19	193	3.9	39
Sr	mg/L	0.01	0.1	0.003	0.03
Tl	mg/L	0.0001	0.001	0.0001	0.0008
U	mg/L	0.0006	0.006	0.0004	0.004
V	mg/L	0.001	0.01	0.0008	0.008
Zn	mg/L	0.05	0.5	0.02	0.2

(a) TDS values are calculated.

(b) Potassium concentrations may be elevated due to inclusion in charge balance.

Shaded cells identify constituents below detectable limits in all samples used to derive input water quality.

Non-detect concentrations assumed equal to the detection limit.

Column leach testing of the artisanal material samples was not performed. Therefore, a similar approach to the estimation of short-term ROM ore stockpile seepage quality could not be adopted. For the short-term ROM stockpiles, it is assumed that, due to its short travel and residence time, the quality of stockpile seepage will be similar to that of runoff. Results from ponded water collected on site are also considered a good analog for short-term ROM ore stockpile seepage quality. Results from water samples collected on site were presented in Table 5.4-8.

6.3.2.5 Summary of Model Simulations

Tables 6.3-5 and 6.3-6 list the mass balance (MB) model simulations conducted to predict ore stockpile runoff and seepage, respectively. These simulations were performed to capture the expected range in ore stockpile runoff and seepage water quality during operations. To assess the effect of geochemical controls (GC), geochemical model simulations were conducted for all simulations. An Eh of 400 mV, representative of oxidizing conditions, was assumed for ore runoff and seepage.

Table 6.3-5 Long-Term Ore Stockpile Runoff and Short-Term ROM Ore Stockpile Runoff/Seepage Model Simulations

Simulation	Input Water Quality Derivation	Model Type	
	Metal Loading Rate(determined from SPLP tests)	Mass Balance (MB)	Geochemical Controls (GC)
Long-Term Ore Stockpile			
LT-O-1A	average (bulk upper ore)_	x	x
LT-O-1B	maximum (bulk upper ore)	x	x
Short-Term ROM Ore Stockpile			
ST-O-1A	artisanal 1	x	x
ST-O-1B	artisanal 2	x	x

Table 6.3-6 Long–Term Ore Stockpile Seepage Model Simulations

Simulation	Input Water Quality Derivation		Model Type	
	Time Period	Ore Stockpile Surface Area	Mass Balance (MB)	Geochemical Controls (GC)
O-2A	first flush (bulk upper ore)	low	x	x
O-2B	first flush (bulk upper ore)	high	x	x
O-2C	long-term (bulk upper ore)	low	x	x
O-2D	long-term (bulk upper ore)	high	x	x

6.3.2.6 Nitrogen Loading

Nitrogen is predicted to be present in ore stockpile seepage and runoff due to flushing of residuals from blasting. Prediction of nitrogen in ore stockpile seepage and runoff applied the same approach as that for the waste rock facility.

The following assumptions, specific to the long-term and short-term ore stockpiles, were applied:

- The average consumption of ANFO during blasting of ore for the first 13 years of production will be 2,050 tonnes per year (Baloo 2006). Approximately two percent of ANFO use will report to the ore stockpiles as blasting residual.
- Average annual runoff and seepage (combined) from the long-term ore stockpile and short-term ROM stockpiles will be 527 and 525 millimeters, respectively (see Table 6.3-1).

- The total surface area of the long-term stockpile (East and West combined) is estimated at 114 hectares (see Table 3.2-1). Assuming a mine life of 13 years, the average annual long-term stockpile footprint area will be 8.8 hectares.

- The total surface area of the short-term ROM stockpiles is estimated at 6 hectares.

The average annual waste rock seepage/runoff nitrogen concentration (i.e., nitrate and ammonia) was calculated assuming 10 percent of the annual nitrogen load is dissolved in the average annual volume of seepage and runoff combined. Estimation of the average annual volume of combined seepage/runoff assumed a stockpile footprint of 8.8 hectares for the long-term stockpile and 6 hectares for the short-term ROM stockpiles.

6.3.3 Ore Stockpile Water Qualities

6.3.3.1 Operational Long-Term Ore Stockpile Runoff and Short-Term ROM Ore Stockpile Runoff/Seepage

Model results for long-term ore stockpile runoff are shown in Table 6.3-7. Because prediction of ore stockpile runoff did not include mixing of water qualities for different rock types, the predictions without geochemical controls (i.e., “no control”) are identical to the assumed water quality inputs. Results for each model simulation are shown with and without the influence of geochemical controls (i.e., precipitation of credible mineral phases and equilibrium with atmospheric carbon dioxide). Minerals predicted to precipitate are identified at the bottom of the table. The final two columns of the table summarize the predicted range in long-term ore stockpile runoff water quality during operations.

For a number of constituents, leachate concentrations were below detectable limits in all SPLP leachates. These constituents are identified in the column labeled “non-detects”. For these constituents (i.e., Ag, Be, Cd, Hg, P, Pb, Se, Tl and U), predicted concentrations likely are biased high because concentrations below detectable limits were assumed equal to the detection limit in all calculations.

The pH of ore stockpile runoff is predicted to range from approximately 6.5 to 7. Dissolved copper and cobalt concentrations on the order of tens to hundreds of micrograms per liter are predicted. Trace metals which are predicted to occur at microgram per liter to tens of micrograms per liter concentrations include: Li, Fe, Mn and Zn.

Table 6.3-7 Long-Term Ore Stockpile Runoff Model Results

Metal Loading Rate		Average		Maximum		Non-Detects [e]	Detection limit [f]	Predicted Range	
Geochemical Controls		No Control	Control	No Control	Control			Max.	Min.
pH	s.u.	6.7	6.6	6.6	6.9			6.9	6.6
alkalinity [g]	mg/L as $CaCO_3$	1.1	1.1	2.1	2.1			2.1	1.1
TDS [d]	mg/L	13	13	18	17			18	13
Ag	mg/L	<0.001	<0.001	<0.001	<0.001	X	0.00005	<0.001	<0.001
Al	mg/L	0.007	0.007	0.01	0.01		0.001	0.01	0.007
As	mg/L	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
B	mg/L	0.02	0.02	0.02	0.02			0.02	0.02
Ba	mg/L	<0.001	<0.001	<0.001	<0.001		0.0002	<0.001	<0.001
Be	mg/L	<0.001	<0.001	<0.001	<0.001	X	0.0002	<0.001	<0.001
Ca	mg/L	0.3	0.3	0.5	0.5			0.5	0.3
Cd	mg/L	<0.001	<0.001	<0.001	<0.001	X	0.00004	<0.001	<0.001
Co [c]	mg/L	0.08	0.08	0.2	0.2			0.2	0.08
Cr	mg/L	<0.001	<0.001	<0.001	<0.001		0.0002	<0.001	<0.001
Cu [c]	mg/L	0.1	0.1	0.2	0.2			0.2	0.1
Fe	mg/L	0.01	<0.001	0.01	<0.001		0.01 [h]	0.01	<0.001
Hg	mg/L	<0.001	<0.001	<0.001	<0.001	X	0.00002	<0.001	<0.001
K	mg/L	2.4	2.4	2.5	2.5			2.5	2.4
Li	mg/L	0.007	0.007	0.01	0.01			0.01	0.007
Mg [c]	mg/L	0.1	0.1	0.2	0.2			0.2	0.1
Mn	mg/L	0.002	0.002	0.003	0.003			0.003	0.002
Mo	mg/L	<0.001	<0.001	<0.001	<0.001			<0.001	<0.001
Na	mg/L	0.9	0.9	1.6	1.6			1.6	0.9
Ni	mg/L	<0.001	<0.001	<0.001	<0.001		0.0002	<0.001	<0.001
P	mg/L	0.03	0.03	0.03	0.03	X	0.03	0.03	0.03
Pb	mg/L	<0.001	<0.001	<0.001	<0.001	X	0.0002	<0.001	<0.001
Sb	mg/L	<0.001	<0.001	<0.001	<0.001		0.0002	<0.001	<0.001
Se	mg/L	<0.001	<0.001	<0.001	<0.001	X	0.0002	<0.001	<0.001
Si	mg/L	2.3	2.3	2.5	2.5			2.5	2.3
Sn	mg/L	<0.001	<0.001	<0.001	<0.001		0.0002	<0.001	<0.001
SO_4 [b]	mg/L	5.3	5.3	7.2	7.2			7.2	5.3
Sr	mg/L	<0.001	<0.001	0.001	0.001		0.0002	0.001	<0.001
Tl	mg/L	<0.001	<0.001	<0.001	<0.001	X	0.00002	<0.001	<0.001

Metal Loading Rate		Average		Maximum		Non-Detects [e]	Detection limit [f]	Predicted Range	
Geochemical Controls		No Control	Control	No Control	Control			Max.	Min.
U	mg/L	<0.001	<0.001	<0.001	<0.001	X	0.0001	<0.001	<0.001
V	mg/L	<0.001	<0.001	<0.001	<0.001		0.0002	<0.001	<0.001
Zn	mg/L	0.003	0.003	0.005	0.005		0.001	0.005	0.003
Minerals Predicted to Precipitate [a]									
ferrihydrite [$Fe(OH)_3$]			X		X				

[a] "X" indicates that the mineral is predicted to precipitate. In some cases, mineral precipitation may be too small to result in a reported reduction in constituent concentrations (i.e., reduction may be less then the number of significant figures reported in the table).

[b] Sulfate concentrations may be elevated due to inclusion in charge balance.

[c] See Section 6.1.2 for a discussion of predicted copper, cobalt and magnesium concentrations for pH values between 6 and 9.

[d] TDS values are calculated.

[e] Constituent not detected in any SPLP leachates used in the prediction of runoff quality.

[f] Detection limit shown for all constituents reporting at least one leachate result below detectable concentrations.

[g] Minimum and maximum alkalinity values determined from the control results only.

[h] All samples at or below detection limit.

Model results for short-term ROM ore stockpile runoff and seepage are shown in Table 6.3-8. Because prediction of ore stockpile seepage/runoff did not include mixing of water qualities for different rock types, the "no control" predictions are identical to the assumed water quality inputs. Results for each model simulation are shown with and without the influence of geochemical controls (i.e., precipitation of credible mineral phases and equilibrium with atmospheric carbon dioxide). Minerals predicted to precipitate are identified at the bottom of the table. The final two columns of the table summarize the predicted range in short-term ROM ore stockpile runoff/seepage water quality during operations.

For a number of constituents, leachate concentrations were below detectable limits in both SPLP leachates. These constituents are identified in the column labeled "non-detects". Since concentrations below detectable limits were assumed equal to the detection limit, for these constituents (i.e., Ag, As, B, Be, Cd, Cl, Cr, F, Fe, Hg, Mo, Sb, Se, SO_4, Tl, U and V), predicted concentrations likely are biased high.

Table 6.3-8 Short-Term ROM Ore Stockpile Runoff/Seepage Model Results

ROM Loading Rate		Artisanal 1		Artisanal 2		Non-Detects [e]	Detection limit [f]	Predicted Range	
Geochemical Controls		No Control	Control	No Control	Control			Max.	Min.
pH	s.u.	5.8	5.5	5.6	5.6			5.8	5.5
alkalinity [g]	mg/L as $CaCO_3$	12	0.1	8.6	0.1			0.1	0.1
TDS [d]	mg/L	113	85	86	66			113	66
Ag	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001
Al	mg/L	0.02	0.02	0.001	0.001		0.001	0.02	0.001
As	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001
B	mg/L	0.1	0.1	0.1	0.1	X	0.1	0.1	0.1
Ba	mg/L	0.02	0.02	0.01	0.01			0.02	0.01
Be	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001
Ca	mg/L	2.8	2.8	2.1	2.1			2.8	2.1
Cd	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001
Cl	mg/L	5.0	5.0	5.0	5.0	X	5.0	5.0	5.0
Co [c]	mg/L	2.9	2.9	2.2	2.2			2.9	2.2
Cr	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001
Cu [c]	mg/L	28	18	22	15			28	15
F	mg/L	0.2	0.2	0.2	0.2	X	0.2	0.2	0.2
Fe	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001
Hg	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001
K	mg/L	1.2	1.2	1.4	1.4			1.4	1.2
Li	mg/L	0.01	0.01	0.009	0.009			0.01	0.009
Mg [c]	mg/L	2.3	2.3	1.7	1.7			2.3	1.7
Mn	mg/L	0.2	0.2	0.06	0.06			0.2	0.06
Mo	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001
Na	mg/L	1.3	1.3	1.3	1.3			1.3	1.3
Ni	mg/L	0.02	0.02	0.02	0.02			0.02	0.02
P	mg/L	0.1	0.1	0.1	0.1		0.1	0.1	0.1
Pb	mg/L	0.005	0.005	0.005	0.005			0.005	0.005
Sb	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001
Se	mg/L	0.01	0.01	0.01	0.01	X	0.01	0.01	0.01
Si	mg/L	4.8	4.8	2.5	2.5			4.8	2.5
Sn	mg/L	0.002	0.002	0.001	0.001			0.002	0.001
SO_4 [b]	mg/L	49	46	37	34	X	5.0	49	34
Sr	mg/L	0.02	0.02	0.01	0.01			0.02	0.01
Tl	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001
U	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001
V	mg/L	0.001	0.001	0.001	0.001	X	0.001	0.001	0.001

Table 6.3-8 Short-Term ROM Ore Stockpile Runoff/Seepage Model Results (continued)

ROM Loading Rate		Artisanal 1		Artisanal 2		Non-Detects [e]	Detection limit [f]	Predicted Range	
Geochemical Controls		No Control	Control	No Control	Control			Max.	Min.
Zn	mg/L	0.2	0.2	0.2	0.2			0.2	0.2
Minerals Predicted to Precipitate [a]									
brochantite [$Cu_4(OH)_6SO_4$]			X		X				

(a) "X" indicates that the mineral is predicted to precipitate. In some cases, mineral precipitation may be too small to result in a reported reduction in constituent concentrations (i.e., reduction may be less then the number of significant figures reported in the table).

(b) Sulfate concentrations may be elevated due to inclusion in charge balance.

(c) See Section 6.1.2 for a discussion of predicted copper, cobalt and magnesium concentrations for pH values between 6 and 9.

(d) TDS values are calculated.

(e) Constituent not detected in any SPLP leachates used in the prediction of runoff quality.

(f) Detection limit shown for all constituents reporting at least one leachate result below detectable concentrations.

(g) Minimum and maximum alkalinity values determined from the control results only.

The pH of short-term ROM ore stockpile runoff/seepage is predicted to range from approximately 5 to 6. This pH prediction is likely conservative (i.e., low), and most representative of the pH values that will be expected during the early stages of mining. The artisanal samples reported lower SPLP leachate pH values than the bulk upper ore sample. The lower buffering capacity of this material, in comparison to the bulk upper ore, is likely attributable to depletion of carbonates in near-surface materials due to weathering. Dissolved copper and cobalt concentrations on the order of milligrams to tens of milligrams per liter are predicted for ROM ore stockpile runoff/seepage. Due to the elevated total copper and cobalt contents of the artisanal samples used to predict short-term ROM ore stockpile runoff/seepage quality, predicted concentrations likely represent an upper limit, and may only be representative of the highest grade ROM ore stockpiles. The lower leachate pH of the artisanal mine samples (in comparison to the bulk upper ore) would also have enhanced metal leaching. Following the initial stages of mining, the long-term ore stockpile runoff/seepage copper and cobalt predictions may be more representative of short-term ROM ore stockpile runoff/seepage. Trace metals that were detected in SPLP leachates that are predicted to occur at microgram per liter to tens of micrograms per liter concentrations include: Li, Ni, Pb and Sn. Manganese and zinc are predicted to occur at concentrations on the order of tens to 100s of micrograms per liter.

6.3.3.2 Operational Ore Stockpile Seepage

Long-term ore stockpile seepage model results are shown in Table 6.3-9. Because prediction of ore stockpile seepage did not include mixing of water qualities from different rock types, the "no control" predictions are equal to the

assumed water quality inputs. Results for each model simulation are shown with and without the influence of geochemical controls (i.e., precipitation of credible mineral phases and equilibrium with atmospheric carbon dioxide). Minerals predicted to precipitate are identified at the bottom of the table. The final two columns of the table summarize the predicted range in long-term ore stockpile seepage water quality during operations.

For a number of constituents, leachate concentrations were below detectable limits in all column leachates used in the prediction of long-term ore stockpile seepage qualities. These constituents are identified in the column labeled "Non-Detects" and for these constituents (i.e., Ag, Be, Cd, F, Fe, Hg, Pb, Sb, Se, Sn and U), predicted concentrations may be biased high due to use of detection limit values in all calculations.

The pH of long-term ore stockpile seepage is predicted to range from approximately 6 to 9. In the absence of geochemical controls, copper and cobalt concentrations up to tens of milligrams per liter are predicted. Geochemical controls should limit peak concentration to the milligram per liter range. The following metals are predicted to be present at concentrations up to 10s of micrograms per liter (list includes only metals detected in column leachates): As, Cr, Mo, Ni and V. Manganese, Li, and Zn are predicted to occur at concentrations up to hundreds of micrograms per liter or milligrams per liter.

6.3.3.3 Ore Stockpile Seepage and Runoff Nitrogen

Ammonia and nitrogen concentrations in ore stockpile seepage and runoff are predicted to be similar to the levels predicted for waste rock seepage and runoff. Assuming that two percent of the annual ANFO use of 2,050 tonnes per year reports to the stockpiles and that 10 percent of this load is solubilized in average annual runoff and seepage from the stockpiles, average annual ammonia and nitrate concentrations of 9 milligrams per liter-N are predicted for both the long-term and short-term ROM ore stockpiles.

Table 6.3-9 Long-Term Ore Stockpile Seepage Model Results

Time Period		First Flush				Long-Term				Non-Detects [e]	Detection limit [f]	Predicted Range	
Surface Area		Low Surface Area		High Surface Area		Low Surface Area		High Surface Area				Max.	Min.
Geochemical Controls		Input	Control	Input	Control	Input	Control	Input	Control				
pH	s.u.	6.2	7.7	6.2	8.4	6.3	7.6	6.3	8.5			8.5	6.2
alkalinity [g]	mg/L as $CaCO_3$	19	15	185	84	12	11	122	98			98	11
TDS [d]	mg/L	98	91	984	761	38	35	380	327			984	35
Ag	mg/L	<0.001	<0.001	0.003	0.003	<0.001	<0.001	0.002	0.002	X	0.00005	0.003	<0.001
Al	mg/L	0.08	0.08	0.8	0.8	0.03	0.03	0.3	0.3			0.8	0.03
As	mg/L	0.003	0.003	0.03	0.03	0.001	0.001	0.01	0.01			0.03	0.001
B	mg/L	0.4	0.4	3.9	3.9	0.1	0.1	1.0	1.0			3.9	0.1
Ba	mg/L	0.009	0.009	0.09	0.02	0.003	0.003	0.03	0.03			0.09	0.003
Be	mg/L	0.001	0.001	0.01	0.01	<0.001	<0.001	0.008	0.008	X	0.0002	0.01	<0.001
Ca	mg/L	1.7	1.7	17	9.3	0.6	0.6	6.3	5.8			17	0.6
Cd	mg/L	<0.001	<0.001	0.003	0.003	<0.001	<0.001	0.002	0.002	X	0.00004	0.003	<0.001
Cl	mg/L	12	12	122	122	0.9	0.9	8.6	8.6			122	0.9
Co [c]	mg/L	1.4	1.4	14	1.1	0.4	0.4	4.0	0.5		0.2	14	0.4
Cr	mg/L	0.003	0.003	0.03	0.03	<0.001	<0.001	0.008	0.008		0.0002	0.03	<0.001
Cu [c]	mg/L	2.4	0.03	24	0.05	0.9	0.03	9.5	0.02			24	0.02
F	mg/L	0.3	0.3	3.2	3.2	0.2	0.2	2.0	2.0	X	0.05	3.2	0.2
Fe	mg/L	0.06	<0.001	0.6	<0.001	0.04	<0.001	0.4	<0.001	X	0.01	0.6	<0.001
Hg	mg/L	<0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001	<0.001	X	0.00002	0.001	<0.001
K [b]	mg/L	21	21	208	208	8.7	8.7	87	87			208	8.7
Li	mg/L	0.1	0.1	1.2	1.2	0.01	0.01	0.1	0.1			1.2	0.01
Mg [c]	mg/L	2.2	2.2	22	17	0.5	0.5	5.2	5.0			22	0.5
Mn	mg/L	0.03	0.03	0.3	0.2	0.01	0.01	0.1	0.09			0.3	0.01
Mo	mg/L	0.005	0.005	0.05	0.05	0.002	0.002	0.02	0.02			0.05	0.002
Na	mg/L	4.3	4.3	43	43	0.4	0.4	3.8	3.8			43	0.4
Ni	mg/L	0.007	0.007	0.07	0.07	0.002	0.002	0.02	0.02			0.07	0.002
P	mg/L	0.2	0.2	1.9	1.9	0.1	0.1	1.4	1.4		0.03	1.9	0.1

Table 6.3-9 Ore Stockpile Seepage Model Results (continued)

Time Period		First Flush				Long-Term				Non-Detects [e]	Detection limit [f]	Predicted Range	
Surface Area		Low Surface Area		High Surface Area		Low Surface Area		High Surface Area				Max.	Min.
Geochemical Controls		Input	Control	Input	Control	Input	Control	Input	Control				
Pb	mg/L	0.001	0.001	0.01	0.01	<0.001	<0.001	0.008	0.008	X	0.0002	0.01	<0.001
Sb	mg/L	0.001	0.001	0.01	0.01	<0.001	<0.001	0.008	0.008	X	0.0002	0.01	<0.001
Se	mg/L	0.001	0.001	0.01	0.01	<0.001	<0.001	0.008	0.008	X	0.0002	0.01	<0.001
Si	mg/L	10	10	104	53	6.4	6.4	64	54			104	6.4
Sn	mg/L	0.001	0.001	0.01	0.01	<0.001	<0.001	0.008	0.008	X	0.0002	0.01	<0.001
SO_4	mg/L	19	19	193	193	3.9	3.9	39	39		1.0	193	3.9
Sr	mg/L	0.01	0.01	0.1	0.1	0.003	0.003	0.03	0.03			0.1	0.003
Tl	mg/L	<0.001	<0.001	0.001	0.001	<0.001	<0.001	<0.001	<0.001		0.00002[h]	0.001	<0.001
U	mg/L	<0.001	<0.001	0.006	0.01	<0.001	<0.001	0.004	0.004	X	0.0001	0.006	<0.001
V	mg/L	0.001	0.001	0.01	0.01	<0.001	<0.001	0.008	0.008		0.0002 [h]	0.01	<0.001
Zn	mg/L	0.05	0.05	0.5	0.5	0.02	0.02	0.2	0.2			0.5	0.02
Minerals Predicted to Precipitate [a]													
malachite [$Cu_2(OH)_2CO_3$]			X		X		X		X				
ferrihydrite [$Fe(OH)_3$]			X		X		X		X				
rhodochrosite [$MnCO_3$]					X				X				
am. silica [SiO_2(am)]					X				X				
dolomite [$CaMg(CO_3)_2$]					X				X				
Sphaerocobaltite [$CoCO_3$]					X				X				
barite [$BaSO_4$]					X								

(a) "X" indicates that the mineral is predicted to precipitate. In some cases, mineral precipitation may be too small to result in a reported reduction in constituent concentrations (i.e., reduction may be less then the number of significant figures reported in the table).

(b) Potassium concentrations may be elevated due to inclusion in charge balance.

(c) See Section 6.1.2 for a discussion of predicted copper, cobalt and magnesium concentrations for pH values between 6 and 9.

(d) TDS values are calculated.

(e) Constituent not detected in any column leachates used in the prediction of seepage quality.

(f) Detection limit shown for all constituents reporting at least one leachate result below detectable concentrations.

(g) Minimum and maximum alkalinity values determined from the control results only.

(h) All samples at or below detection limit.

6.3.3.4 Assumptions

As for the waste rock predictions, the simulation of ore seepage and runoff water quality assumed that the ore is unreactive with respect to sulfide oxidation. ABA and NAG testing of ore samples indicated no potential to generate acidity (see Section 5.3.2). The evaluation of ore water qualities therefore did not need to account for any transient effects resulting from sulfide oxidation within the ore stockpile. Geochemical characterization to date has focused on samples from the oxide ore zone. If ore from the transitional and/or sulfidic zone is to be extracted, the predictions of ore seepage and runoff would need to be re-evaluated.

6.4 OPEN PIT

6.4.1 Introduction

Estimation of the quality of pit lakes during the life of mine and post-closure, requires an integrated assessment of the mine hydrogeology, geochemistry, hydrology and anticipated future limnological conditions. Figure 6.4-1 illustrates schematically the hydrogeological and geochemical processes that may influence long-term pit water quality.

As identified by the general conceptual model (Figure 6.4-1), water in a pit lake will be derived from a number of different sources, including groundwater infiltration through perimeter wall rock, pit wall runoff, surface runoff and direct precipitation.

In addition to hydrological and hydrogeological influences, limnological processes such as lake turn over, density stratification, and wind mixing will affect the lake geochemistry. In particular, the absence or development of a permanent, reducing hypolimnion at the base of the lake may have significant effects on metals mobility in the pit lake. Biota present in the pit lake (e.g., algae) may also affect the behavior and distribution of pit water constituents. Each source must be quantified in terms of its contribution to the total loading of the system. Quantification of the relevant pathways is essential to obtaining an accurate estimate of concentrations and loadings after mixing.

Equation 1 describes a typical mass balance model that is used to model pit lake qualities. Determination of the major and trace elements requires that concentrations of these elements be known in primary sources and sinks, and that those masses of the individual sources and sinks can be estimated from the hydrologic water balance.

$$M_{\min}\sum a_j C^i_{j,\min} + M_{GW}C^i_{GW} + M_{SW}C^i_{SW} - M_E = M_{PW}C^i_{PW} + M_{sed}C^i_{sed} + M_{ss}C^i_{ss} \quad (1)$$

where:

M_{min} = mass release by all minerals in wall rock during water/rock interaction

a_j = mass fractions of different minerals in pit wall rocks

$C^i_{j,min}$ = concentration of element i in different pit wall rock minerals

M_{GW} = mass of groundwater

C^i_{GW} = concentration of element i in groundwater (dissolved, adsorbed and suspended material)

M_{SW} = mass of surface water

C^i_{SW} = concentration of element i in surface water (dissolved, adsorbed and suspended material)

M_E = mass of evaporated water

M_{PW} = mass of pit lake water (less mass of pit overflow water)

C^i_{PW} = concentration of dissolved element i in pit lake water

M_{sed} = mass of bottom sediments

C^i_{sed} = concentration of element i in bottom sediments

M_{SS} = mass of all suspended particulate matter (including organic/inorganic material)

C^i_{SS} = total concentration of element i in suspended particulate matter.

6.4.2 Approach and Methodology

The hydrogeologic investigation of the site was ongoing at the time of document preparation. A detailed water balance had therefore not been developed for the

pit. In the absence of a detailed pit water balance, a different approach than presented in the previous section was followed to estimate pit water qualities during the operational and closure phases. This approach is summarized in Table 6.4-1. It should be noted that the approach used is highly simplified and represents a qualitative attempt at bracketing the possible range of pit lake water qualities.

Table 6.4-1 Summary of Pit Water Quality Modeling Approach

Mining Phase	Estimated Pit Water Quality	Approach
Operation	best-case	assumed to be represented by background groundwater quality
	worst-case	assumed to be represented by waste rock seepage quality – first flushing column leach tests[(a)]
Post-closure	best-case	assumed to be represented by average waste rock runoff quality[(a)]
	worst-case	assumed to be represented by waste rock seepage quality – long-term column leach tests[(a)]

[(a)] As modeled in Section 6.2.

The following assumptions are implicit in the approach summarized in Table 6.4-1:

Operation Phase Pit Water Qualities

- It is assumed that ponding of pit water would be limited during the operational phase to keep the working faces dry for mining. The quality of water accumulating in the pit would therefore resemble a mixture of groundwater and pit wall runoff/seepage quality. During operations, the pit dewatering wells will intercept groundwater prior to flowing into the pit (Feasibility Study – MinProc 2007). Although groundwater inflow into the pit is expected to be minimal, groundwater quality was assumed to be representative of best-case pit water quality as it is representative of water in contact with site rock.
- Instead of trying to utilize a detailed pit water balance to simulate the geochemical conditions within the pit, the waste rock seepage qualities (high surface area, first flush) were used to represent the worst case operational pit water qualities, whereas background groundwater qualities were assumed to represent best case pit water qualities.
- The estimate of the best case pit water quality does not consider pit wall runoff/seepage, which can significantly change the predicted pit water quality during operational phase. The worst case estimate is regarded as

a conservative estimative of the expected pit water quality as it does not account for a groundwater input.

Post-Closure Pit Water Qualities

- On cessation of mining, the dewatering wells will be turned off and the groundwater level will rise, thereby flooding the pit. Surface runoff will also enter the pit contributing to the rise in water level. 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 and the effects of evapo-concentration on the pit lake water quality (Section B2.10 – Baseline Hydrogeology).
- The post mining Kwatebala pit can act as a hydrogeological sink or source, which will influence the long-term water qualities of the pit. The pit lake could become either a groundwater "sink" (groundwater flows into the pit – the steady state pit water level would be below the groundwater level and the pit lake would have no effect on the groundwater quality in the surrounding aquifer) or a groundwater "source" (the steady state pit water level is higher than the surrounding groundwater level and pit lake water would flow out and affect the groundwater quality).
- In the absence of a detailed pit water balance, the modeled average runoff qualities for waste rock were used to represent the best case long-term pit water qualities (see Section 5.1). This input represents rapid surficial runoff originating from, but having limited interaction with, remaining highwall. The worst-case post-closure pit water quality was estimated from the modeled long-term waste rock (high surface area) seepage results. The predicted waste rock seepage with a high surface area was considered to be representative of the large surface area exposed to infiltration and groundwater inflow during mining. This input represents water discharging through the pit wall while experiencing extensive interaction with material in the damaged rock zone.
- This approach is regarded as being conservative since groundwater entering the pit lake will likely be of better quality compared to the seepage and runoff qualities of the pit wall. Therefore, dilution by groundwater (and direct precipitation) may result in lower pit water concentrations compared to the modeled concentrations.
- The above water qualities were speciated in the geochemical modeling code PHREEQC, and the effects of CO_2, mineral solubility and redox changes associated with a pit lake were evaluated to account for geochemical controls.

6.4.3 Modeling

Geochemical speciation modeling was conducted to evaluate potential ion speciation and mineral solubility constraints on the pit water quality for the operational phase and post-closure of the Kwatebala pit. A number of mineral phases observed in ore and waste rock were considered as solubility controls. The saturation indices of these selected mineral phases were assessed to determine if they controlled concentrations of trace metals and major ions in the pit lake. Table 6.4-2 shows predicted water qualities for the operational case both with and without solubility controls.

The pit lake was assumed to be an open system, containing well-oxygenated water (Eh = 400 millivolts), and accounting for reaction with atmospheric carbon dioxide. A fixed fugacity ($PCO_2 = 10^{-3.5}$ atmospheres) was used. The equilibrium with atmospheric CO_2 constitutes a buffered system.

Pit lakes may stratify, depending on pit configuration, seasonal effects, wind activity, density relationships between various inputs to the pit lake, etc. Stratification generally results in an epilimnion (upper water layer) separated from a hypolymnion (lower water layer) by a thermocline or chemocline. Due to a lack of interaction between the atmosphere and the hypolimnion, the geochemical conditions and controls at the bottom of the pit may differ considerably from those in the upper portions of the pit lake. In particular, reducing conditions may exist in a hypolimnion, resulting in metal removal through processes such as sulfide precipitation. Since it is not possible to evaluate pit lake stratification with the information currently available, it is not known whether the Kwatebala pit lake will be stratified or mixed.

6.4.4 Estimated Pit Water Quality

6.4.4.1 Operation Phase

Table 6.4-2 provides the best-case and worst-case estimates of pit water qualities with and without geochemical controls considered during the operation phase for the Kwatebala open pit.

The simulation of the best case pit lake water quality is derived from average groundwater quantitative results sampled from springs around the proposed pit. The worst case pit water quality represents the geochemical modeling results for the first flushing of waste rock samples as derived from waste rock column tests assuming a high surface area.

Table 6.4-2 Estimated Pit Water Qualities during Operation Phase

Parameter	Units	Best-Case		Worst-Case [c]	
		No Controls	Controls	No Controls	Controls
pH	s.u.	7.5	8.6	7.8	8.1
TDS [e]	mg/L	650	214	4,357	2,203
alkalinity	mg/L as $CaCO_3$	444	115	1,476	62
Ag	mg/L	0.004	0.004	0.01	0.01
Al	mg/L	0.01	0.01	2.3	2.1
As	mg/L	0.02	0.02	0.01	0.01
B	mg/L	0.01	0.01	1.3	1.3
Ba	mg/L	0.2	0.2	0.4	0.01
Be	mg/L	na[b]	na[b]	0.01	0.01
Br	mg/L	na[b]	na[b]	1.4	1.4
Ca	mg/L	59	0.4	300	18
Cd	mg/L	na[b]	na[b]	0.01	0.01
Cl[a]	mg/L	4	4	418	418
Co	mg/L	0.1	0.1	0.8	0.8
Cr	mg/L	0.003	0.003	0.01	0.01
Cu	mg/L	0.006	0.006	3.6	0.02
F	mg/L	na[b]	na[b]	13	13
Fe	mg/L	0.07	<0.001	0.01	<0.001
Hg	mg/L	0.001	0.001	0.01	0.01
K[a]	mg/L	2	2	269	269
Li	mg/L	na[b]	na[b]	1.2	1.2
Mg	mg/L	76	32	380	209
Mn	mg/L	0.2	0.1	1.0	1.0
Mo	mg/L	0.004	0.004	0.3	0.3
Na	mg/L	4.4	4.4	192	192
Ni	mg/L	0.01	0.01	0.1	0.1
NH_4	mg/L N	na[b]	na[b]	13	13
NO_3	mg/L-N	na[b]	na[b]	13	13
P	mg/L	0.23	0.23	1.3	1.3
Pb	mg/L	0.02	0.02	0.5	0.08
Sb	mg/L	0.01	0.01	0.01	0.01
Se	mg/L	0.03	0.03	0.1	0.1
Si	mg/L	6.5	6.5	33	33
Sn	mg/L	na[b]	na[b]	0.01	0.01
SO_4 [a]	mg/L	19	19	965	964
Sr	mg/L	0.4	0.4	2.0	2.0
Tl	mg/L	na[b]	na[b]	0.01	0.01
U	mg/L	0.004	0.004	0.01	0.01
V	mg/L	0.01	0.01	0.01	0.01
Zn	mg/L	0.005	0.005	0.2	0.2

Table 6.4-2 Estimated Pit Water Qualities during Operation Phase (continued)

Parameter	Units	Best-Case		Worst-Case [c]	
		No Controls	Controls	No Controls	Controls
Minerals Predicted to Precipitate [d]					
$Al_4(OH)_{10}SO_4$					X
barite [$BaSO_4$]			X		X
cerrusite [$PbCO_3$]					X
dolomite [$CaMg(CO_3)_2$]			X		X
ferrihydrite [$Fe(OH)_3$]			X		X
fluorite [CaF_2]					
magnesite [$MgCO_3$]			X		
malachite [$Cu_2(OH)_2CO_3$]					X
manganite [MnOOH]					X
rhodochrosite [$MnCO_3$]			X		

[a] Sulfate, chloride, and potassium concentrations may be elevated due to inclusion in charge balance.

[b] na – not analyzed.

[c] As modeled in Section 6.1.

[d] "X" indicates that the mineral is predicted to precipitate. In some cases, mineral precipitation may be too small to result in a reported reduction in constituent concentrations (i.e., reduction may be less then the number of significant figures reported in the table).

[e] TDS values are calculated.

The following inferences can be made from the results presented in Table 6.4-2:

- The modeling with geochemical controls and gas equilibrium reactions results in decreased concentrations for the following constituents: Al, Ba, Ca, Mg, Mn, Fe, Cu and Pb.
- The predicted pH of the operational pit lake is neutral to alkaline. When geochemical controls are invoked, pit lake pH increases due to equilibration with atmospheric carbon dioxide. Dolomite is predicted to precipitate. It should be noted that dolomite represents a mineralogical control that may not be achieved throughout the pit lake.
- The total dissolved solids (TDS) predicted for the worst-case pit water quality are an order of magnitude higher than the best case during the operational phase. The high TDS levels are attributed to the following major species; Cl, K, Mg, Na, NO_3, NH_4 and SO_4.

- The worst case simulation predicts a Cu concentration of 3.6 milligrams per liter without geochemical controls. This concentration declines to 20 micrograms per liter when malachite is invoked as a possible solubility control.
- Predicted Ca and Mg concentrations are higher in the worst case than the best-case. This is attributed to the dissolution of dolomite. The solubility of dolomite is higher at pH 8.1 than pH 8.6, as shown for Mg in Figure 6.1-3.
- The cobalt concentration is predicted at 0.1 and 0.8 milligrams per liter for the best-case and worst-case simulations. No mineral controls were identified for Co given the physicochemical properties of the solution. Therefore, Co behavior was conservative for the scenarios modeled.
- The concentration of Al for the worst case scenario is two orders of magnitude higher than the best case. This is attributed to higher Al concentration observed in the waste rock column leach tests than in the groundwater.

6.4.4.2 Long-Term

Geochemical modeling was conducted to estimate the best and worst-case long-term pit water qualities. Table 6.4-3 presents the best and worst case estimates with and without geochemical controls, which were derived from the geochemical modeling results for waste rock runoff (average) and waste rock seepage qualities (long-term with high surface area), respectively.

The following inferences can be made from the results presented in Table 6.4-3:

- The modeling with geochemical controls and gas equilibrium reactions results in decreased TDS levels and lower concentrations of the following constituents: Ba, Ca, Mg, Fe, Cu, Mn, Cd and Zn.
- The predicted pH of the long-term pit lake is alkaline.
- The concentration of dissolved ions (TDS) is predicted to be up to a few hundred milligrams per liter for the best-case (with controls). The TDS for the worst-case prediction with controls was modeled to be almost 6 times higher than the best-case.

Table 6.4-3 Estimated Long-Term Pit Water Qualities (Post-Closure)

Parameter	Units	Best Case [c]		Worst Case [c]	
		No Controls	Controls	No Controls	Controls
pH	s.u.	8.5	8.3	8.2	8.9
TDS [e]	mg/L	116	115	1,021	701
alkalinity	mg/L as $CaCO_3$	58	58	430	220
Ag	mg/L	0.003	0.003	0.01	0.01
Al	mg/L	0.1	0.1	0.2	0.2
As	mg/L	0.003	0.003	0.01	0.01
B	mg/L	na[b]	na[b]	1.3	1.3
Ba	mg/L	0.05	0.05	0.3	0.05
Be	mg/L	0.001	0.001	0.01	0.01
Br	mg/L	na[b]	na[b]	1.3	1.3
Ca	mg/L	14	14	38	0.2
Cd	mg/L	0.002	0.002	0.01	0.005
Cl	mg/L	4.3	4.3	66	66
Co	mg/L	0.06	0.06	0.03	0.03
Cr	mg/L	0.004	0.004	0.02	0.02
Cu	mg/L	0.1	0.02	0.1	0.02
F	mg/L	0.3	0.3	2.8	2.8
Fe	mg/L	0.01	<0.001	0.01	<0.001
Hg	mg/L	<0.001	<0.001	0.01	0.01
K[a]	mg/L	3.8	3.8	262	262
Li	mg/L	na[b]	na[b]	0.07	0.07
Mg	mg/L	8.8	8.8	41	13
Mn	mg/L	0.1	0.1	0.04	0.02
Mo	mg/L	na[b]	na[b]	0.03	0.03
Na	mg/L	1.4	1.4	1.7	1.7
Ni	mg/L	0.01	0.01	0.04	0.04
NH_4	mg/L N	13	13	13	13
NO_3	mg/L-N	13	13	13	13
P	mg/L	0.3	0.3	1.3	1.3
Pb	mg/L	0.003	0.003	0.02	0.02
Sb	mg/L	0.02	0.02	0.01	0.01
Se	mg/L	0.006	0.006	0.1	0.1
Si	mg/L	na[b]	na[b]	18	18
Sn	mg/L	na[b]	na[b]	0.01	0.01
SO_4 [a]	mg/L	13	13	68	68
Sr	mg/L	na[b]	na[b]	0.2	0.2
Tl	mg/L	0.03	0.03	0.01	0.01
U	mg/L	na[b]	na[b]	0.01	0.01
V	mg/L	na[b]	na[b]	0.01	0.01
Zn	mg/L	0.02	0.02	0.9	0.6

Table 6.4-3 Estimated Long-Term Pit Water Qualities (Post-Closure) (continued)

Parameter	Units	Best Case [c]		Worst Case [c]	
		No Controls	Controls	No Controls	Controls
Minerals Predicted to Precipitate [d]					
barite [$BaSO_4$]					X
dolomite [$CaMg(CO_3)_2$]					X
ferrihydrite [$Fe(OH)_3$]			X		X
magnesite [$MgCO_3$]					X
malachite [$Cu_2(OH)_2CO_3$]			X		X
Manganite [MnOOH]					X
otavite [$CdCO_3$]					X
smithsonite [$ZnCO_3$]					X

(a) Sulfate and potassium concentrations may be elevated due to inclusion in charge balance.

(b) na – not analyzed.

(c) As modeled in Section 6.1.

(d) "X" indicates that the mineral is predicted to precipitate. In some cases, mineral precipitation may be too small to result in a reported reduction in constituent concentrations (i.e., reduction may be less then the number of significant figures reported in the table).

(e) TDS values are calculated.

- Cobalt and copper concentrations without controls are predicted at tens to hundreds of micrograms per liter. The precipitation of malachite may decrease copper concentrations to tens of micrograms per liter. No significant concentration changes for cobalt were predicted by the model.
- A comparison between operational and long-term pit lake water quality predictions shows that they generally are similar. Metal concentrations in the long-term may be slightly lower due to a reduced impact from pit wall runoff.

6.4.4.2 Model Assumptions and Limitations

In addition to the assumptions listed in Section 6.1.3, the geochemical modeling of the pit water qualities further assumed that surface reactions (sorption and exchange processes) were not significant. Since some metal removal may occur due to sorption, this particular assumption may have resulted in a conservative estimate of pit lake qualities.

The modeling also did not attempt to simulate the evolution of the pit lake over time. Temporal and seasonal changes in pit lake inflows were therefore not considered. Extreme high and low concentrations can be expected during low and high precipitation conditions, respectively. However the worst case estimated for the operational phase can be said to be representative of pit water qualities after a

low precipitation or dry season after flushing of weathering products. In addition, as mentioned previously, pit lake stratification was not considered.

Full thermodynamic equilibrium is unlikely to be the case for all chemical components throughout the entire pit lake. In particular, redox equilibrium is not commonly achieved in large bodies of water, even when exposed to the atmosphere. However, geochemical evaluations of natural waters over the last few decades have shown that the equilibrium assumption is a powerful tool that in many circumstances produces results that accurately describe the nature of the general chemistry of natural waters.

6.5 TAILINGS STORAGE FACILITY

6.5.1 Introduction

The TSF has been designed as a "zero discharge" facility. As such, the TSF will be lined to prevent seepage to groundwater. The proposed liner system will consist of a geomembrane underlain by compacted in situ clayey silt. TSF supernatant will be evaporated, remain permanently in storage, recycled to the plant for re-use or treated to meet acceptable water standards prior to being discharged to the environment (Section E9). This section presents the approach and results for the prediction of TSF supernatant quality during operations and post closure.

Tailings will be discharged to the TSF as a slurry, at a density of approximately 46 percent solids by mass (Feasibility Study – MinProc 2007). Tailings from the CCD circuit, $Mg(OH)_2$ and FAM will be co-mingled and discharged a single tailings slurry waste. Prior to discharge, the pH of the tailings slurry will be raised from approximately 3 to a target pH value of approximately 10.2 by the addition of lime. Neutralization of the tailings is intended to decrease the aqueous concentrations of many metals by mineral precipitation (e.g., as (oxy) hydroxides and carbonates) and adsorption/co-precipitation reactions. Metals transformed from the aqueous phase to the solid phase during neutralization will be discharged to the TSF as part of the solids component of the tailings slurry. The tailings solids will therefore be comprised of both primary mineral phases (i.e., minerals present in the host ore) and secondary mineral phases formed during neutralization.

The design rates of tailing solids and water discharges to the TSF are 314 and 369 tonnes per hour, respectively (Section A4 – Table A4.10-1). Tailings slurry will be deposited from strategically placed deposition points around the TSF basin. Supernatant is expected to pond in the natural low area that exists at the

northern extremity of the TSF basin. The quality of this supernatant will be a function of the following:

- The composition of the tailings slurry discharge water.
- The reactivity (or stability) of the tailings solids and the interaction between these solids, the overlying supernatant and the atmosphere.
- The quality and volume of other inputs to the tailings pond (i.e., direct precipitation and precipitation that contacts and runs off from the tailings beach).
- The amount of evaporation.

Supernatant water quality will exhibit temporal variability due to changes in: (1) TSF input water qualities; and, (2) the relative volumes of TSF inputs and outputs (i.e., changes in the TSF water balance on a seasonal and annual basis). The quality of TSF discharge will also exhibit temporal variability due to changes in the chemistries and sources of process water. Water used in the process plant will be a mixture of water recycled from the TSF pond and make-up water from a number of "clean" and "impacted" sources including groundwater, pit water and storm water. A preliminary evaluation of the effects of recirculation on TSF pond water quality is presented in Section 6.5.3.2. This report does not evaluate the effects of changes in the other sources of process water on TSF pond water quality.

A mass balance model was developed to evaluate the potential range in TSF supernatant water quality. Results from the TSF water balance (Feasibility Study - MinProc 2007) and the tailings geochemical characterization program were combined to define the physical and geochemical system. The TSF water balance defines the proportions of each input to the TSF over time (i.e., tailings discharge, direct precipitation and tailings beach runoff resulting from precipitation falling on the beach). Representative water qualities were assigned to each TSF inflow based on results from the geochemical characterization program. A simple mixing model was applied to evaluate resultant water quality within the TSF. Sensitivity analyses were conducted to evaluate the effects of variability in input water qualities. The initial mixing model evaluation assumed conservative mixing and therefore did not consider the effects of geochemical reactions on supernatant quality. Geochemical modeling was conducted to evaluate the effects of geochemical controls. Detailed descriptions of the model approach and derivation of inputs are provided in the next section.

6.5.2 Model Approach and Methodology

6.5.2.1 Overview

Prediction of TSF supernatant water quality made use of the results from the TSF water balance to define the physical system. A description of each component of the water balance is provided in Table 6.5-1.

Table 6.5-1 Description of TSF Supernatant Inflows and Outflows

Type	Inflow/Outflow Name	Description
inflow	tailings discharge water	Tailings discharge water is the aqueous component of the tailings slurry discharge.
	direct precipitation	Direct precipitation is rainfall that falls directly into the TSF pond.
	tailings beach runoff	Tailings beach runoff is rainfall that contacts the wet or dry tailings beach and then flows into the tailings pond.
outflow	seepage	Tailings seepage is water that seeps through the liner (i.e., discharges to the groundwater flow system).
	pumped to return water dam (RWD)	RWD discharge is water pumped from the TSF to the RWD.
	tailings retention	tailings pore water
	evaporation	

Results from the tailings geochemical characterization program were applied to define input water qualities for the tailings discharge water and tailings beach runoff. Data collected for the combined tailings (i.e., CCD washed solids and $Mg(OH)_2$) and FAM samples were used as this information is considered most representative of the tailings waste.

The general modeling sequence followed the steps listed below.

1. ***Define input water qualities.*** Water chemistries were estimated for each TSF input using leach test results from the tailings geochemical characterization program. A range of input water qualities was defined for tailings discharge water and tailings beach runoff.
2. ***Calculate mixing ratios.*** Based on the respective volumes for the various TSF inputs, as defined by the water balance, mixing ratios were calculated on a monthly basis.
3. ***Conservative mass balance model.*** Using a monthly time step, the various TSF inputs were mixed in the appropriate proportions and the resultant water composition determined. The total volume of water estimated to evaporate from the TSF during a model time step (i.e., one month) was removed, resulting in concentration of the TSF water quality. The resultant water composition was determined. Mass balance model

simulations were conducted for twenty-year time periods at three stages of tailings pond development (i.e., 31 hectares, 71 hectares and 216 hectares).

4. ***Geochemical mass balance model.*** Using a monthly time step, the various TSF inputs were mixed in the appropriate proportions and the resultant water composition determined, including metals speciation, redox (Eh) and pH, alkalinity, and saturation indices for mineral phases. The total volume of water estimated to evaporate from the TSF during a model time step (i.e., one month) was removed, resulting in concentration of the TSF water quality. Supersaturated mineral phases were identified and evaluated for their likelihood to precipitate from the solution. The effect of equilibrium with appropriate atmospheric gases (i.e., carbon dioxide) was evaluated. After equilibration with the selected solid phases and carbon dioxide, the solution composition was determined anew. Geochemical mass balance model simulations were conducted for twenty-year time periods at three stages of tailings pond development (i.e., 31 hectares, 71 hectares and 216 hectares).

6.5.2.2 Input Water Qualities

The approach for determination of representative water qualities for each TSF input is described below. Input water qualities are shown in Table 6.5-2. Derivation of input water qualities assumed that concentrations of constituents reported as below detectable limits were equal to the detection limit.

Tailings Discharge Water

Supernatant water quality results from the tailings neutralization tests were used to define a range of representative tailings discharge water qualities. Tailings slurry will be neutralized to a target pH value of approximately 10 prior to discharge. As presented in Section 5.6, water quality data are available from neutralization testing of samples of the bench upper tailings, the bulk upper tailings and the combined bulk upper tailings (i.e., tailings and $Mg(OH)_2$). Because the combined tailings samples are considered the most representative of the project tailings, these data were used.

Water quality results are available for three neutralized solutions (i.e., two flume test and one pilot test sample) (see Tables 5.6.1 and 5.6.2). The pH values listed on the samples provided by Hazen for these solutions bracketed the target discharge pH, ranging from 9 to 10. Final measured pH values by CEMI ranged from 7.6 to 8.2. Water quality results from these three solutions were averaged to define the “average” tailings discharge water quality. To bracket the range in possible discharge water qualities, the maximum and minimum concentrations observed in the tailings neutralization program were identified and used for water

quality prediction purposes as well. An Eh of 400 millivolts, representative of oxidizing conditions, was assumed for tailings discharge water.

The neutralization test results used to characterize discharge water quality are for samples that did not include the FAM waste. This is because the decision to combine the FAM waste with the CCD tailings and $Mg(OH)_2$ was made after completion of the flume and pilot testing at Hazen.

SPLP test results are available for both the FAM residue and the combined tailings (Table 5.4-9). Leachate pH values for the two samples were similar, at 6.2 and 6.4 for the FAM and combined tailings leachates, respectively. The FAM leachate, however, reported a much higher conductivity than the combined tailings sample (2,232 vs. 816 micro Siemens per centimeter). The higher conductivity is largely attributable to higher sulfate, calcium and magnesium leachate concentrations for the FAM sample versus the combined tailings sample. The FAM sample also reported elevated cobalt (2.02 vs. 0.0028 milligrams per liter), copper (0.075 vs. 0.0053 milligrams per liter), chromium (0.034 vs. 0.0005 milligrams per liter) and vanadium (0.0063 vs. 0.0004 milligrams per liter) relative to SPLP results for the combined tailings. These results suggest that the addition of FAM to the combined tailings may result in higher concentrations for these constituents.

Adjustment of the neutralization test results to account for the FAM contribution with the available FAM data (i.e., a single SPLP leach test) is, however, not straightforward. The SPLP leach tests and the neutralization tests were conducted at different solid to solution ratios (i.e., 20:1 for the SPLP test and approximately 1:1 for the neutralization tests assuming the combined tailings were approximately 50% solids by mass). As shown in Figure 6.5-1, comparison of concentrations in the combined tailings SPLP test with the combined tailings average neutralization test concentrations shows that, on average, concentrations in neutralization test supernatants were ten times higher than concentrations in the corresponding SPLP leachates. This evaluation considered only those constituents above detectable limits in both leachates. To account for the FAM contribution using the SPLP leachate results, differences in the solid to solution ratio of the two tests would therefore need to be considered.

Difference in leachate pH is a second factor that must be considered in the adjustment of neutralization test results to account for a FAM contribution. The FAM SPLP leachate pH was 6.2; however, the pH of the tailings will be raised to approximately 10 prior to discharge. Raising the pH of the tailings will reduce the concentrations of many constituents. Figure 6.5-2 compares FAM SPLP leachate concentrations to the combined tailings supernatant concentrations prior to neutralization (i.e., at a pH of 2.9). This figure presents data for the same

constituents shown in Figure 6.5-1. For most constituents, supernatant concentrations are at least an order of magnitude higher than the FAM leachate concentrations. In some cases (e.g., Cu and Co), the supernatant concentrations are higher by two orders of magnitude or more.

Although comparison of the FAM and combined tailings leachate results showed enhanced leaching of some constituents from the FAM residue (i.e., SO_4, Ca, Mg, Co, Cu, Cr and V), a decision was made not to adjust the combined tailings neutralization test results to account for the FAM contribution in the model. This decision was based on two considerations. First, the FAM solids will account for only a small portion of the tailings slurry (estimated at 6.5%). Second, the neutralization process is expected to reduce the mobility of most of the constituents identified in FAM SPLP testing as having greater leachability relative to the combined tailings. This assumption should be confirmed with additional testing of samples representative of the entire waste stream once the final waste management plan is determined.

Tailings Beach Runoff

Results from short-term SPLP leach tests were used to define a range of representative tailings beach runoff water qualities. The conditions of the SPLP leach test are considered most representative of the interaction between rainwater and the tailings beach as this test was designed to assess the environmental stability of a waste material following contact with meteoric water. SPLP leach test results for the combined tailings sample and FAM sample were presented in Table 5.4-9.

The approach to determining tailings beach runoff water quality was similar to the one used for waste rock and ore runoff input water qualities. SPLP leach test results were used to define a range of tailings runoff water qualities. The SPLP leach tests applied a 20 : 1 liquid to solid ratio by weight (2,000 milliliters of water to 100 grams of tailings solid). Measured SPLP leachate concentrations were assumed to be representative of “best-case” or “minimum” tailings runoff quality. SPLP leachate concentrations were multiplied by factors of 1.5 and 2 to define “average” and “maximum” tailings runoff qualities. The solution to solid ratio of the SPLP test yields a solution with a TSS value of 50,000 milligrams per liter. The equivalent TSS values for the “average” and “maximum” tailings runoff qualities were therefore 75,000 and 100,000 milligrams per liter, respectively. The expected TSS of tailings runoff is unknown, but it is reasonable to assume that changes in rainfall intensity will result in variable TSS values. For comparison, tailings will be discharged at 46 percent solids, which is equivalent to a TSS value of 460,000 milligrams per liter.

Table 6.5-2 TSF Model Input Water Qualities

Parameter		Tailings Beach Runoff					Tailings Discharge Water				
		Min.	Avg.	Max.	All Non-Detect[a]	Detection Limit[b]	Avg.	Max.	Min.	All Non-Detect[a]	Detection Limit[b]
Equivalent TSS (mg/L)		50,000	75,000	100,000							
pH	s.u.	6.4	6.4	6.4			7.9	7.6	8.2		
Alkalinity	mg/L as $CaCO_3$	9.3	14	19			31	15	45		
Ag	mg/L	0.00005	0.00008	0.0001	x	0.00005	0.00005	0.00005	0.00005	x	0.00005
Al	mg/L	0.002	0.002	0.003		0.001	0.001	0.002	0.001		0.001
As	mg/L	0.003	0.005	0.006			0.017	0.027	0.007		
B	mg/L	0.010	0.015	0.020	x	0.01	0.01	0.01	0.01		0.01
Ba	mg/L	0.034	0.051	0.067			0.027	0.037	0.013		
Be	mg/L	0.0002	0.0003	0.0004	x	0.0002	0.0002	0.0002	0.0002	x	0.0002
Ca	mg/L	210	315	420			644	696	598		
Cd	mg/L	0.00004	0.00006	0.00008	x	0.00004	0.00004	0.00004	0.00004	x	0.00004
Cl	mg/L	2.7	4.1	5.5		0.5	49	122	13		
Co	mg/L	0.13	0.20	0.27			0.013	0.024	0.006		
Cr	mg/L	0.003	0.004	0.005			0.006	0.008	0.003		
Cu	mg/L	0.010	0.015	0.020			0.017	0.023	0.012		
F	mg/L	0.040	0.060	0.080			0.33	0.48	0.030		
Fe	mg/L	0.010	0.015	0.020		0.01	0.010	0.010	0.010	x	0.01
Hg	mg/L	0.00002	0.00003	0.00004	x	0.00002	0.00002	0.00002	0.00002	x	0.00002
K	mg/L	1.1	1.6	2.1			10	22	4.4		
Li	mg/L	0.005	0.008	0.011			0.059	0.065	0.047		
Mg	mg/L	3.6	5.3	7.1			79	206	5.0		
Mn	mg/L	0.0009	0.001	0.002			0.007	0.011	0.004		
Mo	mg/L	0.010	0.016	0.021			0.26	0.37	0.12		
Na	mg/L	1.9	2.9	3.9			48	111	15		
Ni	mg/L	0.0005	0.0008	0.001		0.0002	0.002	0.002	0.001		
NO_3	mg/L	-	-	-			0.67	1.3	0.30		

Table 6.5-2 TSF Model Input Water Qualities (continued)

Parameter		Tailings Beach Runoff					Tailings Discharge Water				
		Min.	Avg.	Max.							
P	mg/L	0.059	0.089	0.12			0.26	0.70	0.03		0.03
Pb	mg/L	0.0002	0.0003	0.0004	x	0.0002	0.0002	0.0002	0.0002	x	0.0002
Sb	mg/L	0.0009	0.001	0.002		0.0002	0.010	0.011	0.009		
Se	mg/L	0.002	0.004	0.005			0.027	0.034	0.023		
Si	mg/L	4.4	6.6	8.9			33	58	8.3		
Sn	mg/L	0.0002	0.0003	0.0004		0.0002	0.0003	0.0003	0.0002		0.0002
SO_4	mg/L	510	765	1020			1,837	2,000	1,690		
Sr	mg/L	0.39	0.58	0.77			1.4	2.3	1.0		
Tl	mg/L	0.00003	0.00005	0.00006			0.0001	0.0002	0.0001		
U	mg/L	0.0001	0.0002	0.0002		0.0001	0.0003	0.0005	0.0001		0.0001
V	mg/L	0.0008	0.001	0.002			0.002	0.003	0.001		
Zn	mg/L	0.001	0.002	0.002	x	0.001	0.002	0.002	0.001		0.001

(a) Constituent not detected in any SPLP leachates used in the prediction of input water quality.

(b) Detection limit shown for all constituents reporting at least one leachate result below detectable concentrations.

Non-detect concentrations assumed equal to the detection limit.

The final composition of tailings slurry is expected to be as follows: 91.4 weight percent CCD underflow, 6.5 weight percent FAM, 1.4 weight percent lime and 0.7 weight percent $Mg(OH)_2$. For each constituent, results from the FAM and combined tailings SPLP tests were mixed in the following proportions to define a loading rate: 6.5 percent FAM and 93.5 percent combined tailings.

Comparisons of SPLP metal loading rates to metal loading rates derived from the NAG and column tailings leach tests for selected parameters (i.e., Al, As, Co, Cu, Mn and Mo) are shown in Figures 6.5-3 to 6.5-8. For both the bench and combined tailings samples, metal loading rates derived from the short-term SPLP leach test are generally equal to or higher than the metal loading rates derived from the columns. The decision to use the SPLP results over the column test results to predict metal leaching is therefore a conservative assumption. For most parameters shown in Figures 6.5-3 to 6.5-8, metal loading rates calculated from the NAG test results are higher than those calculated from the SPLP results. Because the highly oxidizing and more aggressive conditions of the NAG test are not considered representative of site conditions, it was considered appropriate to omit these data in the prediction of beach runoff qualities.

The total suspended solids (TSS) concentration of tailings beach runoff is estimated to range from 50,000 to 100,000 milligrams per liter, representative of a range of rainfall intensities. Prediction of tailing beach runoff quality assumed that: (1) metal leaching will be proportional to the TSS concentration; and (2) that the calculated average SPLP loading rates are representative of the amount of a metal that will be leached, on a mass basis, from tailings solids suspended in beach runoff. Tailings beach runoff qualities for runoff with TSS values of 50,000, 75,000 and 100,000 milligrams per liter were calculated by multiplying the SPLP loading rates by the TSS concentration. For example, the calculated copper loading rate for a mixture of the combined tailings and FAM was 0.20 milligrams per kilogram of solid. The copper concentration of runoff with a TSS concentration of 50,000 milligrams per liter (or 0.05 kilograms per liter) is then estimated at 0.01 milligrams per liter (0.20 milligrams per kilogram x 0.05kilograms per liter). An Eh of 400 millivolts, representative of oxidizing conditions, was assumed for tailings beach runoff.

Precipitation

Direct rainfall was assumed to be pure water containing no total dissolved solids (TDS). This is a reasonable assumption because the typical TDS of precipitation is a few milligrams per liter, which is negligible compared with that of the other inputs to the TSF. The pH of the direct rainfall was set at 5.7, which is in accordance with the value for pH resulting from interaction between pure water and atmospheric carbon dioxide. An Eh of 400 millivolts was assumed.

6.5.2.3 TSF Mixing Ratios

The dynamic TSF water balance estimates the monthly inflow and outflow volumes to the TSF. Development of the dynamic TSF water balance is described in the Feasibility Study (MinProc 2007). The inflows and outflows from the TSF pond were listed in Table 6.5-1. Water enters the TSF as rainfall or as part of the tailings slurry. Water leaves the TSF pond as seepage through the bottom of the TSF (negligible) and as evaporation from the surface of the TSF. Water is also pumped from the TSF to the return water dam (RWD) for temporary storage prior to re-use in the process plant. This report includes a preliminary evaluation of the effect of recirculation through the process plant on tailings water quality. A detailed evaluation of the effect of recirculation on tailings pond water quality would require additional information on the compositional characteristics of this re-used water. Water is also retained within the pore space of the tailings. This pore water is excluded from the estimate of TSF supernatant volume.

Prediction of TSF supernatant water quality applied water balance results for the base case parameters as follows:

- Tailings solids concentration – 46 percent.
- Tailings specific gravity – 2.65.
- TSF liner consists of geomembrane liner over compacted native soil.

Prediction of TSF supernatant water quality used water balance results for a range of tailings pool sizes (i.e., 31 hectares, 71 hectares and 216 hectares). The TSF water balance was developed using a 30-year precipitation record (Figure 6.5-9). A constant mean annual evaporation (MAE) of 1,772 millimeters was assumed (Feasibility Study - MinProc 2007).

The 30-year model simulation captured both wet and dry precipitation years. Precipitation recurrence intervals calculated for the site are shown in Table 6.5-3. These recurrence intervals are presented on Figure 6.5-9. The model years with total annual precipitation closest to the recurrence intervals are shown in the final column of Table 6.5-3.

Table 6.5-3 TSF Water Balance Simulations

Water Balance	Mean Annual Precipitation (mm)	Approx. Model Year
base case	1,302	2008
100-Year Wet	1,780	2010
10-Year Wet	1,602	2011
100-Year Dry	813	2032
10-Year Dry	997	2028 and 2027

Model predictions of TSF water quality simulated a 20-year period from 2007 to 2026. The model simulation period therefore included a precipitation year representative of average precipitation conditions (year 2008). Precipitation years representative of the estimated 10-year and 100-wet conditions were also captured (years 2011 and 2010). Annual precipitation for the final year of the model simulation (year 2026) is close to the 10-year dry condition. The modeled time period did not capture the 100-year dry event.

6.5.2.4 Tailings Solids

Prediction of TSF supernatant water quality assumed that the tailings are unreactive with respect to sulfide oxidation. ABA and NAG testing of the bench upper and bulk upper tailings indicated no potential to generate acidity as the sulfide contents of the tailings samples were low (see Section 5.3.2). The evaluation of tailings supernatant water quality therefore did not need to account for any transient effects resulting from sulfide oxidation (in particular, generation of acidic conditions and oxidation products) within the tailings. Because geochemical characterization to date has included only samples from the upper ore zone, this assumption (i.e., a lack of acid generation potential) should be re-evaluated as additional characterization data representative of tailings from the lower ore zone, which may contain more sulfides, become available.

Quantitative prediction of supernatant water quality also assumed that metals immobilized during neutralization remain in the solid phase. The solids component of the tailings slurry discharge will include secondary minerals precipitated during neutralization (e.g., copper hydroxide and iron (oxy)hydroxide). These mineral phases may include trace metals in their structure, resulting from co-precipitation or adsorption reactions. The environmental stability of the tailings solids (i.e., secondary precipitates and sorbed metals) following discharge to the environment will be dependent on stability of geochemical conditions within the pond. Changes in tailings pond

supernatant pH or the redox condition within the pond may result in the release of metals previously attenuated during neutralization.

The solubility of many minerals is pH and redox dependent. Solubility curves for malachite, copper hydroxide, cobalt carbonate and dolomite as a function of pH were presented in Section 6.1.2. These figures illustrate that a reduction in the pH of tailings supernatant following discharge may result in the dissolution of metal hydroxide and carbonate phases, resulting in increases in aqueous metal concentrations. Metals attenuated by adsorption/co-precipitation with iron and aluminum hydroxides will also be released if these minerals become unstable.

Changes in supernatant pH could also result in changes in the degree of adsorption. Sorption reactions are also both pH and redox dependent. These variables control the distribution of species in solution as well as the charge of mineral surfaces, factors that influence the affinity of a particular constituent for a sorbent. Sorption edges presented by Smith (1999) for a number of trace metals onto iron oxides are shown in Figure 6.5-10. This figure illustrates that, as conditions become more acidic, cationic trace metals tend to desorb and sorption of anions will increase. A reduction in tailing supernatant pH may therefore lead to desorption of some metals, resulting in an increase in their aqueous concentrations.

Possible metals release from tailings solids was not simulated in mass balance or geochemical mass balance model simulations. How these reactions may affect supernatant water quality is addressed qualitatively in Section 6.5.3.5.

6.5.2.5 Summary of Model Simulations

Table 6.5-4 lists the mass balance (MB) model simulations conducted. These simulations were conducted to capture the expected range in TSF supernatant water quality during operations. To assess the effect of geochemical controls (GC), geochemical modeling was conducted for all model simulations. A 20-year period was simulated to evaluate variability in tailings supernatant water quality due to variable climatic conditions. Three simulations (i.e., average, maximum and minimum) were conducted for each water balance scenario to evaluate the effects of variability in input water qualities.

To assess the potential impacts of re-circulation of the tailings water back to the plant, a single model simulation was conducted (the final simulation listed in Table 6.5-4). TSF supernatant will be pumped to the RWD and then returned to the plant. The 30-year TSF water balance estimates an average monthly flow from the RWD to the plant ranging from 153,770 to 164,920 cubic meters for the 216 hectare and 31 hectare simulations, respectively. Average monthly discharge

from the plant to the TSF is estimated at 266,636 cubic meters. Therefore, the water used in processing will be comprised of approximately 60 percent recycled tailings water and 40 percent water from other sources. Recycling of TSF water will likely result in a concentration (i.e., increase in TDS) of the discharged tailings slurry water over time. The recirculation model simulation assumed that process water used in the plant consisted of 60 percent tailings supernatant and 40 percent "clean" make-up water.

Table 6.5-4 TSF Model Simulations

Simulation	Water Balance	Time (years)	Tailings Water Quality		Model Type	
			Discharge Water	Beach Runoff	MB	GC
TSF-31 Avg	31 Ha	2007 to 2026	average	average	x	x
TSF-31 Max			maximum	maximum	x	x
TSF-31 Min			minimum	minimum	x	x
TSF-71 Avg	71 Ha	2007 to 2026	average	average	x	x
TSF-71 Max			maximum	maximum	x	x
TSF-71 Min			minimum	minimum	x	x
TSF-216 Avg	216 Ha	2007 to 2026	average	average	x	x
TSF-216 Max			maximum	maximum	x	x
TSF-216 Min			minimum	minimum	x	x
TSF-216 Avg Recirculation	216 Ha	2007 to 2026	average	average	x	x

6.5.3 TSF Supernatant Water Quality

6.5.3.1 Operation

The primary inflow to the TSF is tailings discharge water. Figure 6.5-11 shows the relative volumes of inputs to the TSF for the 31 hectare TSF as determined by the dynamic water balance model. Over the 20-year simulation period, on a monthly basis, tailings discharge water accounts for approximately 50 to 90 percent of the total TSF supernatant volume. The proportion of direct precipitation and tailings beach runoff varies seasonally. These sources represent a larger input to the TSF supernatant pond volume during the wet season (i.e., October through April) than during the dry season (i.e., May to September). Figure 6.5-12 shows this seasonal variability. This figure also shows differences in the relative proportions of TSF inputs under wet and dry climatic conditions. In dry years, the relative proportion of precipitation decreases resulting in less dilution of TSF supernatant. In dry years, the relative contribution from tailings beach runoff also decreases. Evaporation is modeled to be relatively constant under variable climatic conditions (Figure 6.5-13). The TSF pond reaches its peak annual pond volume toward the end of the wet season (Figure 6.5-13).

Figures 6.5-14 and 6.5-15 show the relative volumes of inputs to the TSF for the 71 hectare and 216 hectare water balance scenarios. Figures 6.5-16 and 6.5-17 illustrate the differences between the three water balance scenarios. As the size of the TSF pond increases, the relative proportion of precipitation and tailings beach runoff to the tailings pond discharge increases (Figure 6.5-16). The relative amount of evaporation also shows an increasing trend as pond size increases (Figure 6.5-17).

The pH of TSF supernatant is expected to range from approximately 6.5 to 8.5. The dominant cation and anion are expected to be calcium and sulfate, respectively. The primary sources of these constituents are the tailings discharge water. Sulfate is a residual product from the copper and cobalt leaching process. Calcium is elevated due to the addition of lime during neutralization. Assuming no recycling of TSF supernatant, mass balance model results suggest that the maximum TDS of the pond water will be on the order of 6,000 milligrams per liter. The mass balance approach is conservative, and as such does not consider possible reduction in concentration due to mineral precipitation and/or sorption. Precipitation of gypsum should be effective at maintaining TDS levels below the level predicted by the conservative mass balance model. Peak predicted sulfate concentrations following gypsum precipitation are approximately 3,500 milligrams per liter. Water quality predictions assuming likely geochemical controls are discussed further later in this section.

Mass balance and geochemical model results for selected parameters (i.e., Cu, Co, SO_4, As, Mo and Se) for the 31 hectare simulation are shown in Figures 6.5-18 to 6.5-21. Results for the same six parameters for the 71 hectare and 216 hectare model simulations are shown in Figures 6.5-22 to 6.5-29. The following general observations are made with respect to predicted pond water quality:

- ***Model input water qualities*** – Predicted TSF pond water qualities are generally insensitive to variability in the assumed TSS for tailings beach runoff. Predicted TSF water quality is most sensitive to variability in the assumed qualities for tailings discharge water.
- ***Seasonal variability*** - TSF supernatant pond water concentrations are predicted to peak at the end of the dry season (i.e., August to September). Pond water concentrations will be lowest during the wet season.
- ***Annual variability (variable climatic conditions)*** – TSF pond water concentrations are predicted to be inversely correlated to mean annual precipitation. A wet year will result in dilution of TSF supernatant quality (i.e., lower concentrations). Under dry conditions, pond water concentrations will generally increase.
- ***Water balance variability*** – The 216 hectare water balance scenario typically predicted the highest TSF supernatant concentrations. This

observation is likely attributable to greater evaporation for the 216 hectare TSF pond relative to the smaller pond sizes.

TSF supernatant water quality modeling results (without recirculation) are shown in Table 6.5-5. These results are the minimum and maximum predicted concentrations for the three water balance scenarios: 31, 71 and 216 hectares. The results reflect the range for both conservative mixing and with geochemical controls.

To evaluate the potential for geochemical controls to reduce pond water concentrations, geochemical modeling was conducted for all mass balance model scenarios. Table 6.5-5 lists secondary mineral phases that may limit dissolved phase concentrations. Results for selected parameters (i.e., Cu, Co, SO_4, Ca, As, Se and Mn) are shown in Figures 6.5-18 to 6.5-29 for simulations with and without geochemical controls. In these figures, conservative mass balance results are shown as solid symbols and geochemical modeling results are shown as open symbols. In the absence of geochemical controls, the geochemical model results plot on top of the mass balance results (e.g., Mo and Se). It should be noted that the geochemical controls identified in Table 6.5-5 may not be effective for all model simulations. For example, Figure 6.5-18 shows copper results for the 31 hectare simulation. In this model simulation, TSF pond water is predicted to be undersaturated with respect to malachite, the possible copper mineral control listed in Table 6.5-18. In the absence of this geochemical control, the geochemical model results plot on top of the mass balance results in Figure 6.5-18.

Without geochemical controls, peak copper concentrations on the order of tens of micrograms per liter are predicted for the three water balance simulations. The peak predicted copper concentration for the 216 hectare simulation was 50 micrograms per liter. Geochemical model results suggest that precipitation of malachite may limit pond water copper concentrations to 30 micrograms per liter (Figure 6.5-26).

TSF supernatant cobalt concentrations are predicted to range from microgram per liter to hundreds of micrograms per liter. As shown in Figures 6.5-18, 6.5-22 and 6.5-26, sphaerocobaltite is not predicted to be a control on cobalt concentrations at these levels.

Table 6.5-5 TSF Model Supernatant Water Quality Results (No Recirculation)

Water Balance		31 Hectare		71 Hectare		216 Hectare		All		Possible Geochemical Controls	All Non-Detect[a]	Detection Limit[b]
		Min	Max	Min	Max	Min	Max	Min	Max			
pH	s.u.	7.1	8.2	6.8	8.2	6.5	8.2	6.5	8.2			
alkalinity	mg/L as $CaCO_3$	14	53	14	66	17	103	14	103			
Ag	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		x	0.00005
Al	mg/L	<0.001	0.002	0.001	0.003	0.001	0.005	0.001	0.005			0.001
As	mg/L	0.005	0.03	0.005	0.04	0.004	0.06	0.004	0.06			
B	mg/L	0.009	0.01	0.009	0.01	0.01	0.02	0.009	0.02			0.01
Ba	mg/L	0.005	0.04	0.005	0.05	0.005	0.09	0.005	0.09	Barite ($BaSO_4$)		
Be	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		x	0.0002
Ca	mg/L	487	819	395	1,024	338	1,603	338	1,603	Calcite ($CaCO_3$)		
Cd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		x	0.00004
Cl	mg/L	10	144	8	180	6	280	6	280			0.5
Co	mg/L	0.007	0.06	0.008	0.09	0.01	0.2	0.007	0.2			
Cr	mg/L	0.003	0.009	0.003	0.01	0.003	0.02	0.003	0.02			
Cu	mg/L	0.01	0.03	0.01	0.03	0.01	0.05	0.01	0.05	Malachite ($Cu_2(OH)_2CO_3$)		
F	mg/L	0.03	1	0.03	1	0.04	1	0.03	1			
Fe	mg/L	<0.001	0.01	<0.001	0.01	<0.001	0.02	<0.001	0.02	Ferrihydrite ($Fe(OH)_3$)		0.01
Hg	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		x	0.00002
K[c]	mg/L	8	254	6	318	4	495	4	495			
Li	mg/L	0.04	0.08	0.03	0.1	0.02	0.1	0.02	0.1			
Mg	mg/L	4	242	4	303	4	472	4	472			
Mn	mg/L	0.003	0.01	0.003	0.02	0.002	0.03	0.002	0.03			
Mo	mg/L	0.09	0.4	0.07	0.5	0.05	0.8	0.05	0.8			
Na	mg/L	12	131	9	163	6	254	6	254			
Ni	mg/L	<0.001	0.003	<0.001	0.003	<0.001	0.005	<0.001	0.005			0.0002

Table 6.5-5 TSF Model Supernatant Water Quality Results (No Recirculation) (continued)

Water Balance		31 Hectare		71 Hectare		216 Hectare		All		Possible Geochemical Controls	All Non-Detect[a]	Detection Limit[b]
		Min	Max	Min	Max	Min	Max	Min	Max			
P	mg/L	0.03	0.8	0.03	1.0	0.04	2	0.03	2			0.03
Pb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		x	0.0002
Sb	mg/L	0.007	0.01	0.005	0.02	0.003	0.03	0.003	0.03			0.0002
Se	mg/L	0.02	0.04	0.01	0.05	0.01	0.08	0.01	0.08			
Si	mg/L	7	68	6	85	6	133	6	133	Amorphous Silica (SiO_2(am))		
Sn	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			0.0002
SO_4[c]	mg/L	1,363	3,008	1,092	3,764	899	5,878	899	5,878	Gypsum ($CaSO_4$:$2H_2O$)		
Sr	mg/L	0.8	3	0.7	3	0.6	5	0.6	5			
Tl	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			
U	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001			0.0001
V	mg/L	0.001	0.003	0.001	0.004	<0.001	0.006	0.001	0.006			
Zn	mg/L	<0.001	0.002	<0.001	0.003	<0.001	0.005	<0.001	0.005			0.001

(a) Constituent not detected in any leachates used in the prediction of input water quality.

(b) Detection limit shown for all constituents reporting at least one leachate result below detectable concentrations.

Non-detect concentrations assumed equal to the detection limit.

(c) Sulfate and potassium concentrations may be elevated due to inclusion in charge balance.

Gypsum is expected to be an effective control on pond water sulfate and calcium concentrations. Geochemical modeling also identified calcite as a control on calcium concentrations. Geochemical model results show peak sulfate and calcium concentrations on the order of 3,000 milligrams per liter and 600 milligrams per liter, respectively, due to gypsum and/or calcite precipitation (Figures 6.5-19, 6.5-23 and 6.5-27).

Geochemical modeling did not identify a control on aqueous arsenic concentrations (Figures 6.5-20, 6.5-24 and 6.5-28). Arsenic attenuation due to sorption is one mechanism that may limit arsenic mobility. Arsenic may be sorbed onto clays, iron oxides, aluminum hydroxides and organic material. Because iron concentrations are predicted to be low in TSF pond water, adsorption of arsenic onto iron (oxy)hydroxides is not expected to be very effective, and was not simulated. For the prediction of TSF pond water qualities, arsenic is assumed to be conservative.

The following additional possible mineral controls were identified for some or all simulations: ferrihydrite [$Fe(OH)_3$], amorphous silica [SiO_2(am)] and barite [$BaSO_4$]. These minerals might limit the aqueous concentrations of iron, silicon and barium, respectively.

Simulation of TSF pond water qualities over a 20-year period facilitates evaluation in trends in TSF supernatant water quality over the operational period. In general, predicted TSF pond water concentrations are relatively stable over the 20-year period. Although seasonal fluctuations in water quality are observed, less variability is predicted on an annual basis. The model results do not predict significant increases in concentration over time due to the cumulative effects of evaporation on pond water quality. It should be noted that, recirculation of tailings water through the process plant, which could lead to a further increase in concentration over time, has not been accounted for in the results presented in Table 6.5-5.

6.5.3.2 Recirculation

Recirculation will likely result in increased concentrations of some constituents in tailings discharge water. In particular, constituents whose concentrations are not controlled by precipitation of secondary minerals (e.g., Na and Cl) will be expected to increase. This section presents a preliminary evaluation of the effect of recirculation through the process plant on tailings water quality. A detailed evaluation of the effect of recirculation on tailings pond water quality would require additional information on the compositional characteristics of this re-used water.

It is assumed that the water used in the plant will be a mixture of water recycled from the TSF pond and water from other sources (e.g., groundwater, site runoff). The assumed ratio of TSF pond water to water from other sources is 0.6: 0.4. The recirculation model simulation assumed that water mixed with the TSF pond water is unimpacted and does not represent a source of trace metals or major ions (i.e., the composition of distilled water). In reality, the water mixed with the TSF pond water for use in the process plant will contribute some TDS.

Figure 6.5-30 shows the increasing concentration trend for a generic chemical constituent assuming a 60 percent rate of recycle. An initial concentration of 10 milligrams per liter is assumed. The make-up water mixed with the recycled solution is assumed to not contribute any constituent load. Initially, a rapid increase in concentration is observed. The solution stabilizes at a maximum concentration of approximately 25 mg/L. Therefore, in the absence of geochemical controls, constituent concentrations in tailings pond discharge are expected to increase by a factor of 2.5 if the tailings pond contribution to the process water stream is 60 percent.

The 216 hectare TSF model simulation yielded the highest pond water concentrations. To evaluate the effect of recirculation over a 20-year period, a simulation was conducted in which average tailings pond discharge constituent concentrations were increased by a factor of 2.5 over the entire 20-year simulation period. Although it would take a number of cycles through the process plant for this increase to be observed, the model simulation assumed a 2.5 increase from the start of the modeled period. The average composition of tailings beach runoff was assumed.

Recirculation model results are shown in Table 6.5-6. This table also includes the average simulation results without recirculation to allow for a direct comparison of predicted water qualities with and without recirculation. Both conservative mass balance (i.e., in the absence of geochemical controls) and geochemical model results with mineral phase controls are shown. Recirculation model simulations results for selected parameters (i.e., Cu, Co, SO_4, Ca, As, Se and Mn) are shown in Figures 6.5-31 to 6.5-34. In the absence of geochemical controls, concentration of tailings discharge water by a factor of 2.5 results in a factor of 2.5 increase in TSF pond concentrations. As shown in Figure 6.5-31, in the absence of geochemical controls, peak pond water copper concentrations are predicted to increase to 0.1 milligrams per liter. Precipitation of malachite is predicted to reduce copper concentrations to tens of micrograms per liter. In the absence of a geochemical control on sulfate concentrations, the model predicts peak concentrations greater than 10,000 milligrams per liter. However, precipitation of gypsum is predicted to limit peak sulfate concentrations to less than 4,000 milligrams per liter (Figure 6.5-32).

Table 6.5-6 TSF Model Supernatant Water Quality Results – 216 Hectare Average Case With and Without Recirculation

Simulation		Average Case – Without Recirculation				Average Case – With Recirculation				Possible Geochemical Controls
Geochemical Controls		No Control		Control		No Control		Control		
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
pH	s.u.	6.7	7.8	7.7	7.8	7.0	7.7	7.8	7.8	
Alkalinity	mg/L as $CaCO_3$	20	72	19	23	35	180	21	26	
Ag	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Al	mg/L	0.002	0.003	0.002	0.003	0.003	0.008	0.003	0.008	
As	mg/L	0.009	0.04	0.009	0.04	0.02	0.1	0.02	0.1	
B	mg/L	0.01	0.02	0.01	0.02	0.02	0.06	0.02	0.06	
Ba	mg/L	0.04	0.06	0.005	0.006	0.06	0.2	0.005	0.01	Barite ($BaSO_4$)
Be	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001	
Ca	mg/L	422	1,481	592	634	742	3,690	551	610	Calcite ($CaCO_3$)
Cd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Cl	mg/L	19	113	19	113	44	283	44	284	
Co	mg/L	0.02	0.1	0.02	0.1	0.06	0.1	0.06	0.1	
Cr	mg/L	0.005	0.01	0.005	0.01	0.008	0.03	0.008	0.03	
Cu	mg/L	0.02	0.04	0.02	0.03	0.02	0.1	0.03	0.03	Malachite ($Cu_2(OH)_2CO_3$)
F	mg/L	0.1	0.8	0.1	0.8	0.3	1.9	0.3	1.9	
Fe	mg/L	0.01	0.02	<0.001	<0.001	0.02	0.06	<0.001	<0.001	Ferrihydrite ($Fe(OH)_3$)
Hg	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
K	mg/L	4.5	24	4.5	24	10	59	10	59	
Li	mg/L	0.02	0.1	0.02	0.1	0.05	0.3	0.05	0.3	
Mg	mg/L	30	182	30	182	69	455	110	406	
Mn	mg/L	0.003	0.02	0.003	0.02	0.007	0.04	0.007	0.04	
Mo	mg/L	0.09	0.6	0.09	0.6	0.2	1.5	0.2	1.5	

Table 6.5-6 TSF Model Supernatant Water Quality Results – 216 Hectare Average Case With and Without Recirculation (continued)

Simulation		Average Case – Without Recirculation				Average Case – With Recirculation				Possible Geochemical Controls
Geochemical Controls		No Control		Control		No Control		Control		
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
Na	mg/L	18	109	18	109	41	272	41	273	
Ni	mg/L	0.001	0.003	0.001	0.003	0.002	0.009	0.002	0.009	
P	mg/L	0.1	0.6	0.1	0.6	0.3	1.5	0.3	1.5	
Pb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001	
Sb	mg/L	0.004	0.02	0.004	0.02	0.009	0.06	0.009	0.06	
Se	mg/L	0.01	0.06	0.01	0.06	0.02	0.2	0.02	0.2	
Si	mg/L	15	76	18	51	32	191	50	51	Amorphous Silica (SiO_2(am))
Sn	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.002	
SO_4	mg/L	1,128	4,300	1,636	2,217	2,057	10,717	1,935	3,150	Gypsum ($CaSO_4$:$2H_2O$)
Sr	mg/L	0.9	3.3	0.9	3.3	1.6	8.3	1.6	8.3	
Tl	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
U	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.002	
V	mg/L	0.002	0.005	0.002	0.005	0.003	0.01	0.003	0.01	
Zn	mg/L	0.002	0.004	0.002	0.004	0.002	0.01	0.002	0.01	

(a) Sulfate and potassium concentrations may be elevated due to inclusion in charge balance.

Non-detect concentrations assumed equal to the detection limit.

Table 6.5-7 TSF Model Supernatant Water Quality Results (With Recirculation)

Water Balance		31 Hectare		71 Hectare		216 Hectare		All		All Non-Detect[a]	Detection Limit[b]
		Min.	Max.	Min.	Max.	Min.	Max.	Min	Max[c]		
pH	s.u.	7.1	8.2	6.8	8.2	6.5	8.2	6.5	8.2		
alkalinity	mg/L as $CaCO_3$	14	53	14	66	17	103	14	103		
Ag	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	x	0.00005
Al	mg/L	<0.001	0.006	0.001	0.007	0.001	0.01	0.001	0.01		0.001
As	mg/L	0.005	0.08	0.005	0.1	0.004	0.2	0.004	0.2		
B	mg/L	0.009	0.03	0.009	0.04	0.01	0.06	0.009	0.06		0.01
Ba	mg/L	0.005	0.1	0.005	0.1	0.005	0.2	0.005	0.2		
Be	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001	x	0.0002
Ca	mg/L	487	2,047	395	2,561	338	4,008	338	4,008		
Cd	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	x	0.00004
Cl	mg/L	10	359	8	449	6	699	6	699		0.5
Co	mg/L	0.007	0.1	0.008	0.2	0.01	0.5	0.007	0.5		
Cr	mg/L	0.003	0.02	0.003	0.03	0.003	0.04	0.003	0.04		
Cu	mg/L	0.01	0.07	0.01	0.08	0.01	0.1	0.01	0.1		
F	mg/L	0.03	1.4	0.03	2	0.04	3	0.03	3		
Fe	mg/L	<0.001	0.03	<0.001	0.04	<0.001	0.06	<0.001	0.06		0.01
Hg	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	x	0.00002
K[d]	mg/L	8	635	6	795	4	1,237	4	1,237		
Li	mg/L	0.04	0.2	0.03	0.2	0.02	0.4	0.02	0.4		
Mg	mg/L	4	606	4	758	4	1,179	4	1,179		
Mn	mg/L	0.003	0.03	0.003	0.04	0.002	0.06	0.002	0.06		
Mo	mg/L	0.09	1.1	0.07	1	0.05	2	0.05	2		
Na	mg/L	12	327	9	409	6	636	6	636		
Ni	mg/L	<0.001	0.007	<0.001	0.008	<0.001	0.01	<0.001	0.01		0.0002
P	mg/L	0.03	2.1	0.03	3	0.04	4	0.03	4		0.03
Pb	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001	x	0.0002

Table 6.5-7 TSF Model Supernatant Water Quality Results (With Recirculation) (continued)

Water Balance		31 Hectare		71 Hectare		216 Hectare		All		All Non-Detect[a]	Detection Limit[b]
		Min.	Max.	Min.	Max.	Min.	Max.	Min	Max[c]		
Sb	mg/L	0.007	0.03	0.005	0.04	0.003	0.06	0.003	0.06		0.0002
Se	mg/L	0.02	0.1	0.01	0.1	0.01	0.2	0.01	0.2		
Si	mg/L	7	170	6	213	6	332	6	332		
Sn	mg/L	<0.001	<0.001	<0.001	0.001	<0.001	0.002	<0.001	0.002		0.0002
SO_4[d]	mg/L	1,363	7,521	1,092	9,410	899	14,696	899	14,696		
Sr	mg/L	0.8	7	0.7	8	0.6	13	0.6	13		
Tl	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.001		
U	mg/L	<0.001	0.001	<0.001	0.002	<0.001	0.003	<0.001	0.003		0.0001
V	mg/L	0.001	0.008	0.001	0.01	<0.001	0.01	0.001	0.01		
Zn	mg/L	<0.001	0.006	<0.001	0.007	<0.001	0.01	<0.001	0.01		0.001

(a) Constituent not detected in any leachates used in the prediction of input water quality.

(f) Detection limit shown for all constituents reporting at least one leachate result below detectable concentrations.

Non-detect concentrations assumed equal to the detection limit.

(c) Maximum predicted values are without geochemical controls.

(d) Sulfate and potassium concentrations may be elevated due to inclusion in charge balance.

Table 6.5-6 presents the predicted range in TSF pond water concentrations assuming that recirculation results in a factor of 2.5 increase in peak predicted concentrations. The peak predicted concentrations assume no geochemical controls.

6.5.3.3 Operation Summary

TSF supernatant water quality is expected to exhibit both seasonal and annual variability. Peak constituent concentrations are expected to occur at the end of the dry season. During the wet season, dilution will result in lower TDS and metal concentrations.

Table 6.5-8 summarizes the expected range in constituent concentrations over the operational period. Maximum predicted concentrations are for simulations without geochemical controls. The concentration ranges presented in this table incorporate the results of the recirculation modeling (i.e., a factor of 2.5 increase in peak predicted concentrations). For some metals (e.g., Ba, Cu, and Mn), secondary mineral precipitation may control pond water concentrations. Precipitation of gypsum is expected to be an effective control on dissolved sulfate and calcium concentrations.

For a number of constituents (i.e., Ag, Be, Cd, Hg and Pb), TSF model inputs were derived from solutions that reported concentrations below detectable limits. For these constituents, predicted TSF pond water concentrations are likely biased high.

6.5.3.4 Long-term

At the end of operations, tailings slurry will no longer be discharged to the TSF. At closure, the only inputs to the TSF will be direct precipitation and tailings beach runoff. The outflows from the TSF will include evaporation and a minimal amount of seepage. Tailings pond water will no longer be pumped to the RWD.

The closure plan for the TSF is discussed in Section D5. At closure, a waste rock cover will be placed over the tailings. An evaporative pool will be established at the topographical low. During most storm events, beach runoff and direct precipitation will be retained within the evaporative pool. A spillway will be constructed to facilitate controlled release of water from the evaporative pond during extreme storm events. Due to the low sulfide content of the tailings, the tailings are predicted to be unreactive with respect to sulfide oxidation.

Table 6.5-8 Summary of Predicted Ranges in TSF Supernatant Water Quality

Parameter	Concentration Range						
	µg/L or Below	10s µg/L	100s µg/L	mg/L	10s mg/L	100s mg/L	1000s mg/L or Above
SO_4 [(a)]						x	x
Ca						x	x
K [(a)]				x	x	x	x
Mg				x	x	x	x
alkalinity					x	x	
Cl				x	x	x	
Na				x	x	x	
Si				x	x	x	
Sr			x	x	x		
F		x	x	x			
P		x	x	x			
Mo		x	x	x			
Li		x	x				
Co	x	x	x				
As	x	x	x				
Ba	x	x	x				
Cu	x	x	x				
Se	x	x	x				
B	x	x					
Cr	x	x					
Fe	x	x					
Mn	x	x					
Sb	x	x					
Ni	x	x					
Al	x	x					
Zn	x	x					
V	x	x					
Cd [(b)]	x						
Sn	x						
U	x						
Hg [(b)]	x						
Pb [(b)]	x						
Be [(b)]	x						
Ag [(b)]	x						
Tl	x						

(a) Sulfate and potassium concentrations elevated due inclusion in charge balance.

(b) Constituents below detectable limits in all solutions used to derive model input water qualities.

Shaded cells identify parameters whose ranges increased due to re-circulation.

Development of a preliminary post-closure water balance for the evaporative pond is presented in the Feasibility Study (MinProc 2007). At closure, inputs to the evaporative pond include direct precipitation, tailings beach runoff and tailings infiltration. Tailings infiltration is defined as precipitation that falls onto the tailings beaches and infiltrates through the tailings prior to discharge to the evaporative pond. The primary outflow from the evaporative pond is evaporation.

The evaporative pond water balance was used to assess potential long-term changes in pond water quality resulting from annual variability in climatic conditions (i.e., annual variability in the amount of precipitation versus evaporation). The objective of this modeling effort was to evaluate temporal trends in evaporative pond pH and constituent concentrations as opposed to predict absolute pond water concentrations post closure.

The model simulated a 20-year period following closure. The initial TSF pond water volume was assumed to be approximately 200,000 cubic meters. Results of the post-closure water balance were used to calculate the relative volumes of inputs (i.e., direct precipitation, beach runoff and beach infiltration) and output (i.e., evaporation) to total pond volume over the 20-year period. Figures 6.5-35 and 6.5-36 show monthly precipitation and evaporation, respectively, as a percentage of total tailings pond (or evaporative pond) volume for selected model years. Annual variability in total pond volume for the same model years is shown in Figure 6.5-37. Predicted pond volume for the entire water balance model period (i.e., forty years) is shown in Figure 6.5-38.

During the wet season, direct precipitation is predicted to be the dominant input to the tailings pond. As shown in Figures 6.5-35 and 6.5-37, during periods of relatively low total pond volume (e.g., years 1, 4, 7 and 8 shown as black symbols), wet season direct precipitation accounts for approximately 30 to 70 percent of the total pond volume. When total pond volume is low, a greater proportion of the total pond volume is predicted to evaporate (Figure 6.5-36). As shown in Figure 6.5-36, in some years, the entire pond is predicted to evaporate during the dry season (shown as 100 percent evaporation in Figure 6.5-36).[1] As the total pond volume increases, the relative contribution of precipitation and evaporative losses decreases.

Tailings pond water quality was modeled in PHREEQC over a 20-year period. The initial quality of the TSF pond water was assumed to be represented by the average results for the 216-hectare operational model simulation (average results from the 20-year model simulation with recirculation and geochemical controls were used). Average beach runoff water quality was assumed. The quality of

[1] To ensure geochemical model convergence, periods of 100% evaporation (as indicated by the water balance model) were simulated as 95% evaporation.

beach infiltration was assumed to be equivalent to that of the initial TSF pond water quality.

Model results for selected parameters are shown in Figures 6.5-39 to 6.5-43. All model simulations included geochemical controls. Equilibrium with atmospheric carbon dioxide at a partial pressure of $10^{-3.5}$ atmospheres was assumed for the first simulation (shown as closed symbols in Figures 6.5-39 to 6.5-43) but not for the second simulation (shown as open symbols in Figures 6.5-39 to 6.5-43).

The model results indicate that pond water quality will be influenced by the relative amounts of precipitation and evaporation. For the first few modeled years when total pond volume is relatively small, evaporation results in significant increases in pond water concentrations during the dry season. Relatively high precipitation volumes (i.e., relative to total pond volume) also result in greater dilution during the early stages of the model simulation during the wet season. During the latter stages of the model simulation as total pond volume increases, pond water concentrations are more stable. It should be noted that the 20-year model simulation ended during a period of peak predicted pond volumes (as shown in Figure 6.5-38). If the model simulation was extended to include the next 20 years, the annual variability in pond water concentrations would be expected to increase (as observed during the early stages of modeling).

Post-closure, neutralized tailings slurry will no longer be discharged to the TSF. The tailings slurry is expected to provide some buffering capacity due the presence of excess unreacted limestone or lime. It was hypothesized that tailings pond pH values may decrease post closure due to a larger relative contribution from direct precipitation. Precipitation is the tailings pond input assumed to have the lowest pH. The post-closure model simulation results suggest that, provided equilibrium with atmospheric carbon dioxide is achieved, pond water pH will remain near-neutral and relatively stable (Figure 6.5-39). If equilibrium with carbon dioxide is not maintained, at times, pH may decline to values of approximately 6. As the pH on the pond water decreases, there is greater potential for remobilization of metals from the tailings solids.

6.5.3.5 Assumptions

Tailings Solids Stability

Prediction of supernatant water quality assumed that the tailings solids are stable following discharge (i.e., the tailings solids are not a source of metals). Stability testing of the bulk upper tailings over an approximately one-month period showed a slight decline in pH and an increase in supernatant conductivity following exposure to the atmosphere. Supernatant pH stabilized at approximately 8.2 to 8.3, likely representative of a calcite-buffered system in equilibrium with atmospheric carbon dioxide. Analysis of supernatant leachate following

approximately one month of atmospheric interaction indicated that re-mobilization of metals was generally low. In some cases, greater metal attenuation (i.e., a reduction in constituent concentrations) was observed. Stability testing of the combined tailings mixture (i.e., tailings, $Mg(OH)_2$ and FAM solids) has not been conducted. The stability of these tailings may differ from that observed for the bulk upper tailings.

The stability of the tailings under reducing conditions also has not been evaluated. During neutralization of the tailings, some metals may be attenuated by adsorption or co-precipitation with iron (oxy)hydroxides. If mildly reducing conditions were to develop at depth, such metals might be released due to reductive dissolution of the iron (oxy)hydroxides. This could result in elevated metals concentrations in tailings seepage relative to the supernatant. Alternatively, precipitation of metal sulfides might occur if conditions became strongly reducing, resulting in removal of dissolved metals from the tailings pore water.

Sample Representativeness

As was discussed in Section 6.1.3, a fundamental assumption inherent to the prediction of mine water qualities is that the input water chemistries used in the modeling are representative of their respective input sources. The TSF model assumes that tailings solids and supernatant samples generated during flume and pilot testing conducted by Hazen are representative of the wastes that will be generated during mining.

The project description (Section A4) indicates that effluent from the mine site sewage treatment plant will be used as process water in the plant. Treated effluent will likely add nutrients and biological oxygen demand (BOD) to the tailings discharge. The impact of water treatment plant effluent on tailings discharge has not been addressed in this report.

The project description (Section A4 – Table A4.4-1) lists other wastes (in addition to tailings) that will be disposed of in the TSF (e.g., solid acid plant waste from filters, crud (solid), liquid laboratory waste and liquid neutralized acid plant waste). GRD MinProc provided the following information on the quantity and composition of these wastes (Gerrans 2007).

- ***Acid plant waste from filters***: It is estimated that 750 tonnes of solid acid plant filter waste will be generated each year. The acid plant filters capture the impurities contained in the sulfur. The composition of this waste will therefore depend on the quality of the sulfur received (Gerrans 2007).
- ***Crud***: It is estimated that 240 tonnes of solid crud waste will be generated each year. Crud is composed of fines that are removed from

the pregnant leach solution (PLS) feed to the solvent extraction unit by the addition of an organic coagulant. The crud waste will therefore contain some organics (Gerrans 2007).

- ***Laboratory waste (liquid)***: It is estimated that 200 tonnes of liquid laboratory waste will be generated each year. This waste will include organics, acids and bases (Gerrans 2007).
- ***Neutralized acid plant waste***: It is estimated that 4,000 tonnes of neutralized acid plant liquid waste will be generated each year. This waste will be neutralized with lime, limestone or caustic prior to discharge to the TSF (Gerrans 2007).

Because these wastes have not yet been generated, their environmental stability was not evaluated. In comparison to the mass of tailings waste generated annually (i.e., > 5 million tonnes (solids + liquid), the relative masses of the wastes listed above are very small. Although these additional wastes could impact TSF water quality, because they constitute a very small fraction of the total waste, TSF pond water quality is expected to be dominated by the tailings waste chemical signature.

Potential impacts from non-tailing waste streams have not been addressed in this report.

TSF Supernatant vs. Seepage Quality

For the impact assessment, predicted tailings supernatant quality is assumed to be representative of tailings seepage quality. This assumption does not imply that tailings pore water quality at any point in time will be the same as the supernatant, but rather that the range in predicted supernatant qualities captures the expected range in seepage quality. Pore water at depth may be more concentrated than at surface at a particular time due to greater interaction (i.e., longer contact time and lower solution to solid ratio) between the aqueous and solid phases.

7 PROJECT WATER QUALITY STANDARDS/GUIDELINE EVALUATION

7.1 INTRODUCTION

TFM Project "applicable" (i.e., required under the terms of the Mining Convention) and "reference" (i.e., not required but represent good practice in other jurisdictions) water quality process effluent discharge limits are presented in Table A2.7-8 of the ESIA (Section A2 – Legal Policy and Framework). This table lists applicable effluent standards promulgated by the World Bank Group and project-defined reference standards promulgated by the Democratic Republic of the Congo (DRC) and the United States Environmental Protection Agency (US EPA). TFM Project reference water quality guidelines for surface waters are presented in Table A2.7-9 of the ESIA (Section A2 – Legal Policy and Framework). This table lists drinking water, agricultural and ambient surface water guidelines promulgated by the following organizations and governments: the US EPA, the World Health Organization (WHO) and South Africa. It should be noted that the project mine and process plant effluent management system is being designed under a zero discharge concept, which will mean the use of proven and feasible state-of-the-art engineering and technology for the design, construction, operation and closure of a facility, in order to eliminate or minimize discharges from the facilities to the environment. Limits that would normally apply to process effluent discharges are World Bank Group effluent limits for mining and milling operations (World Bank 1995) and base metal and iron ore mining (World Bank 1998a). All other effluent guidelines are not legally applicable under the terms of the Mining Convention and are provided as a reference for comparison purposes only (Section A2 – Legal Policy and Framework).

This section presents a general discussion of selected parameters predicted to potentially exceed "applicable" or "reference" water quality standards in mine waters (i.e., waste rock facility seepage and runoff, ore stockpile seepage and runoff, TSF supernatant and the pit lake). The comparison of predicted mine water qualities to the project water quality guidelines does not imply that mine waters will impact the type of water for which a guideline is derived (for example, comparison of TSF supernatant water quality to guidelines for agricultural purposes does not imply that tailings water is likely to be used for this purpose). Also, the comparison of predicted mine water qualities to the project water quality guidelines does not necessarily mean that discharge of water with containment concentrations higher than the reference guidelines is legally prohibited (Section A2 – Legal Policy and Framework). The water quality guidelines include both "applicable" and "reference" guidelines. Reference guidelines are being used by TFM to provide a conservative guide for crafting TFM water

management plans, and are not legally applicable to the TFM project. The information presented in this section will also be considered in the evaluation of mitigation measures.

This section does not present an exhaustive review of all modeled parameters, but rather highlights a few key constituents of potential concern that are considered diagnostic of overall water quality and possible exceedances of "applicable" or "reference" water quality standards or guidelines. These include the following:

- pH.
- Sulfate.
- Metals (arsenic, copper, cobalt).
- Nutrients (nitrate).
- Radioactivity and uranium.

All water quality predictions presented in this document assume mining and processing of oxide ore only. Neither transitional nor sulfide ore is proposed to be extracted in the project phase covered by this ESIA. If sulfide-bearing ore and waste are extracted in the future, different conditions may arise in the mine facilities depending on the acid generation characteristics of these more sulfidic ores and their waste products. In particular, conditions may become more acidic, with higher concentrations for sulfate and TDS, as well as enhanced metal leaching.

7.2 COMPARISON OF MODEL RESULTS TO STANDARDS FOR SELECTED PARAMETERS

All references to applicable and reference water quality standards provided in the following sections are based on the data presented in Tables A2.7-8 and A2.7-9 (Section A2 – Legal Policy and Framework).

7.2.1 pH

The acceptable pH range for mining effluents ranges from 6 to 9 (World Bank, DRC and US EPA standards) (Table A2.7-8). The acceptable pH range for drinking water is 6.5 to 8.5 (US EPA and WHO) (Table A2.7-9). The project agricultural and ambient surface water guidelines fall within these ranges or are less restrictive.

The predicted pH of most mine waters is expected to range from 6 to 9. Due to the low total sulfur content of the oxide waste rock, ore and tailings, generation of ARD is not expected within the mine facilities. Leach testing results for artisanal materials did indicate a potential to yield leachates with pH values less than 6. These results were used to predict ROM ore stockpile runoff and seepage, resulting in predicted pH values below 6 for these facilities. Prior to discharge to the TSF, the pH of the tailings slurry will be raised from approximately 3 to a target pH value of approximately 10 by the addition of lime. The pH of the tailings slurry will therefore likely exceed the World Bank Effluent upper limit of 9.0. The pH of the TSF supernatant may also be greater than 9 at times. However, interaction with atmospheric carbon dioxide and dilution with rainwater is expected to lower the TSF supernatant pH below this value at the time of discharge to the TSF. The pH of the pit lake is predicted to generally meet the project reference guidelines, ranging from 7.5 to 8.9.

7.2.2 Sulfate

There is no project applicable or reference standard for sulfate concentrations in mine effluent (Table A2.7-8). The US EPA secondary drinking water standard for sulfate is 250 milligrams per liter (Table A2.7-9). US EPA secondary drinking water standards are non-enforceable guidelines regulating contaminants that may cause cosmetic effects or aesthetic effects (e.g., taste, odor, or color) in drinking water. The USEPA recommends secondary standards to water systems but does not require compliance. Elevated sulfate concentrations in mine waters are typically the result of ARD (i.e., release of sulfate following oxidation of sulfide minerals). Because the sulfide content of the waste rock generated during mining of the oxide ore is expected to be low, the potential for the generation of ARD is very low.

Sulfate concentrations in ore stockpile and waste rock facility runoff are predicted to be in the milligram per liter to tens of milligrams per liter range. These levels are similar to the sulfate concentrations measured SPLP and column leach test leachates. Sulfate leaching is attributed to dissolution of soluble sulfate minerals (e.g., jarosite and gypsum). Peak predicted waste rock facility seepage concentrations exceed the 250 milligrams per liter ”reference” guideline for drinking water. Because waste rock seepage quality was assumed to be representative of worst-case operational pit lake water quality, the worst-case operational phase pit lake water quality prediction also exceeds the 250 milligrams per liter reference guideline.

TSF supernatant sulfate concentrations will likely exceed the 250 milligrams per liter guideline. Sulfate, a residual product from the use of sulfuric acid in the copper and cobalt leaching process, is present at elevated concentrations (a few

thousand milligrams per liter) in tailings discharge water. TSF modeling predicted peak TSF sulfate concentrations of thousands of milligrams per liter. Gypsum has been identified as a possible secondary mineral phase control on TSF sulfate concentrations; however, gypsum will only reduce peak sulfate concentrations to a few thousand milligrams per liter.

7.2.3 Metals

7.2.3.1 Arsenic

Water quality results from the baseline study indicate that dissolved arsenic is present in site waters (Section B.12). Water quality results from the 2006 baseline sampling events reported peak dissolved arsenic concentrations of 1 and 2 µg/L in surface water and groundwater samples, respectively (Tables B2.12-7 and B2.12-11). Water quality results from the 1997/1998 baseline sampling events reported higher peak concentrations (i.e., up to 98 micrograms per liter in surface water (Table B2.12-8) and 12 micrograms per liter in groundwater (Table B2.12-12)). Baseline fish monitoring indicated elevated arsenic levels in fish tissue (Section B3.3). These data suggest that arsenic is naturally occurring and mobile in site waters.

Leach testing of waste rock and ore samples generally yielded leachates with arsenic concentrations ranging from below detectable limits to a few micrograms per liter. The tailings demonstrated the greatest potential for arsenic leaching, yielding column leachate concentrations up to approximately 0.1 milligrams per liter for the upper bench tailings and approximately 0.06 milligrams per liter for the combined tailings. The World Bank and DRC effluent standards for arsenic are 400 micrograms per liter and 100 micrograms per liter, respectively (Table A2.7-8). The US EPA and WHO drinking water standards for arsenic are 10 micrograms per liter (Table A2.7-9). Mine water quality predictions indicate that TSF supernatant arsenic concentrations may at times exceed this standard. Ore stockpile seepage arsenic concentrations are also predicted to exceed 10 micrograms per liter at times. Arsenic concentrations in waste rock facility seepage and runoff and ore stockpile runoff are predicted to likely meet the drinking water standards.

7.2.3.2 Copper

The geochemical characterization program demonstrated that copper leaching is pervasive for all mine wastes (i.e., waste rock and tailings) and ore. The primary oxide ore copper mineral phase is malachite which means that copper is present in a relatively labile form. Leach test results indicated a relationship between leachate copper concentrations consistent with the solubility curve for malachite

(i.e., as pH decreases below circum-neutral values, copper leachate concentrations increase).

The World Bank and EPA mine effluent standards for copper are 300 micrograms per liter. The DRC mine effluent standard for copper is 1,500 micrograms per liter (Table A2.7-8). The US EPA and WHO drinking water standards for copper are one and two milligrams per liter, respectively (Table A2.7-9). US EPA's chronic surface water guideline for the protection of aquatic life is the strictest of the project defined reference guidelines. This guideline is hardness dependent, ranging from 2 to 4 micrograms per liter for the hardness levels observed in study area streams. The South African agricultural guideline of 200 micrograms per liter falls between the drinking water and surface water guidelines.

Copper concentrations in all mine waters (i.e., waste rock facility seepage/runoff, ore stockpile seepage/runoff, TSF supernatant and pit lake water) are predicted to likely exceed the chronic surface water guideline. Mine water quality predictions also indicate that exceedance of the South African agricultural guideline is likely is most mine waters. At times, copper concentrations in ore stockpile seepage (long-term and ROM), waste rock seepage, ROM stockpile runoff and pit water quality may also exceed the drinking water guidelines.

7.2.3.3 Cobalt

The South African guideline of 50 micrograms per liter for agricultural purposes is the only project defined water quality reference guideline (Table A2.7-9). Similar to copper, cobalt leaching was pervasive for all mine wastes and ore. Mine water quality modeling results indicate a potential for exceedances of the above standard in all mine waters (i.e., waste rock seepage/runoff, ore stockpile seepage/runoff, TSF supernatant and pit water).

7.2.4 Nutrients

The US EPA and WHO drinking water standards for nitrate are 10 milligrams per liter-N and 11.3 milligrams per liter-N, respectively. Because ANFO will be used as the primary blasting agent, nitrate is predicted to be present in waste rock seepage and runoff due to the flushing of blasting residuals. Nitrate in waste rock seepage and runoff is predicted to exceed the above drinking water limits during operations. Nitrate concentrations are predicted to decrease post-closure as the readily soluble blasting residue is flushed from the waste rock facility. Predicted nitrate concentrations in long-term and ROM stockpile runoff and seepage are close to the standards. Based on the expected level of accuracy of mine water quality predictions (order of magnitude at best), exceedances are possible. Nitrate

concentrations in the pit lake are also predicted to exceed the drinking water standards.

7.2.5 Radioactivity and Uranium

Stakeholders for the project have identified radioactivity as a concern. Table A2.7-9 lists the following project defined reference standards for radioactivity and uranium:

- ***Gross Alpha*** - The US EPA and WHO drinking water standards for alpha particles are 15 picocuries per liter and 0.5 Bequerels per liter, respectively.

- ***Gross Beta*** – The US EPA and WHO drinking water standards for beta particles and photon emitters are 4 millirems per year and 1 Becquerel per liter, respectively.

- ***Uranium*** – The South African guideline for agricultural purposes is the strictest project defined reference guideline (10 micrograms per liter). The US EPA and WHO drinking water standards are 30 and 15 micrograms per liter, respectively.

Predictions of uranium concentrations in mine waters were presented in Section 6. Peak predicted waste rock seepage uranium concentrations are equivalent to the South African agricultural guideline of 10 micrograms per liter. However, because this prediction is based on leachate results that were typically below detectable limits, exceedance of the guideline is considered unlikely.

A review of all radioactivity data collected as part of the geochemical characterization study was conducted by Golder personnel with radioactivity expertise. Documentation of this review is provided in Attachment A. This review evaluated data collected as part of the geochemical characterization study. The conclusions of this study were as follows:

1. **Tailings Supernatant** – Based on the geochemical characterization results, tailings discharge water is expected to be compliant with project defined reference guidelines for uranium, gross alpha and gross beta. Because recirculation may result in higher concentrations of radioactive species, ongoing monitoring during operations is recommended. It is possible that, at closure, enough uranium and its daughter products could be present to release measurable radon.

2. **Waste Rock and Ore Stockpile Runoff and Seepage** – Analysis of uranium and thorium in the ore and waste rock indicates that special precautions and permitting for the stockpiles and waste rock facilities will not be necessary.

7.2.6 Summary

This section presented a comparison of predicted mine water qualities to "applicable" and "reference" water quality standards or guidelines. Direct comparison of predicted mine water quality predictions to standards must consider the expected accuracy of the predictions (i.e., order of magnitude). Due to use of detection limit values in this document, predicted concentrations for some parameters likely are biased high. This must be taken into account when comparing predicted concentrations against standards, as illustrated in the following example.

The US EPA drinking water standard for thallium is 2 micrograms per liter. The predictions of thallium concentrations in waste rock seepage and runoff were based on leachate results in which thallium was consistently below detectable limits. In some cases, the detection limit for thallium was higher than the drinking water standard. Therefore, although thallium is predicted to range from 0.001 to 0.01 milligrams per liter in waste rock seepage and from 0.001 to 0.03 milligrams per liter in waste rock runoff, it is not appropriate to conclude that an exceedance of the drinking water standard is likely. Using the available data, thallium concentrations in waste rock runoff and seepage therefore cannot be predicted with a reasonable degree of certainty. The detection limit for tailings leachates was much lower (i.e., less than 0.1 micrograms per liter). The predicted thallium concentration in the TSF is predicted to be less than 1 microgram per liter. Other parameters whose predicted concentrations may be affected in a similar manner include Ag, B, Cd, Fe, P, Sb, Se and V.

8 WATER AND WASTE MANAGEMENT

8.1 WASTE ROCK FACILITY

Waste rock materials that will be generated from the mining of the oxide ore from the planned Kwatebala open pit have the following characteristics that require consideration in the ESIA and mine planning:

- The oxide waste rock is unlikely to generate acid rock drainage.
- The comparison against project-defined water quality reference guidelines presented in Section 7 has identified that seepage and runoff from the oxide waste rock facility may contain sulfate, metals (e.g., copper, cobalt) and nitrate at concentrations exceeding project-defined water quality reference guidelines.
- If transition zone ore and/or sulfide ore is extracted from the deeper parts of the pit, the associated waste rock is expected to have a range of acid rock drainage potentials. Disposal of this waste rock may therefore result in acidic discharges that contain metals and TDS in concentrations higher than predicted for oxide waste rock. These materials are not proposed for mining in this phase of the project.

Based on the characteristics for the oxide waste rock material, the following recommendations for mine planning are proposed:

- An operational waste rock management plan needs to be implemented to ensure that the oxide waste rock facilities only receive materials with oxide characteristics. Such a monitoring program needs to make use of waste rock classification criteria that can be implemented rapidly and easily. These criteria generally are based on a characterization program developed in support of waste rock management. Examples of commonly used criteria include visual characteristics (e.g., lithology, alteration type, vein density, etc.), sulfur content, paste pH, NAG pH, metal content, etc. Should significant amounts of transitional material and/or sulfide waste rock be generated, the need for special handling (e.g., segregation and selective placement, use of alkaline amendments, enhanced cover design, etc.) will require further evaluation.
- An ongoing water quality monitoring program is required to identify environmental risks during operation and post-closure.
- Recommended mitigation measures for long-term control of seepage and runoff should focus on minimizing generation of contact water. This can be achieved through a number of measures, including the following:
  - Placement of an engineered cap and reclamation.

  - Compaction of intermediate and final waste rock facility surfaces.
  - Contouring of final waste rock facility surface to enhance runoff and minimize infiltration.
  - Capture, conveyance and storage of contact water.
- Collection and proper handling of contact water (runoff and seepage) may be needed if potential impacts to water resources are identified. Such measures may include, but not be limited to:
  - Active or passive water treatment (e.g., wetland).
  - Retention and use in the mine water circuit.
  - Retention and controlled release.
  - Groundwater interception mechanisms (e.g., interception boreholes, trenches, reactive barriers).

8.2 ORE STOCKPILES

Ore will be deposited into multiple stockpiles, including two large low-grade stockpiles and up to six smaller short-term ROM stockpiles for high-grade ore being blended and fed to the process plant. The ore materials that will be generated from the mining of the oxide ore from the planned Kwatebala open cast pit have the following characteristics that require consideration in the EISA and mine planning:

- The oxide ore is unlikely to generate acid rock drainage.
- The comparison against water quality reference guidelines presented in Section 7 has identified that seepage and runoff from ore stockpiles may contain sulfate, metals (e.g., arsenic, copper, cobalt) and nitrate at concentrations exceeding project-defined water quality reference guidelines.
- The ESIA addresses mining of the oxide ore only. If transition zone ore and/or sulfide ore is extracted from the deeper parts of the pit, it is expected to have a range of acid rock drainage potentials. Stockpiling of this material may therefore result in acidic discharges that contain metals and TDS in concentrations higher than predicted for oxide ore.

Based on the characteristics for the oxide ore, the following recommendations for mine planning are proposed:

- An ongoing water quality monitoring program is required to identify environmental risks during operation.

- Collection and proper handling of contact water (runoff and seepage) may be needed if potential impacts to water resources are identified. Such measures may include, but not be limited to:
  - Active or passive water treatment (e.g., wetland).
  - Retention and use in the mine water circuit.
  - Retention and controlled release.
  - Groundwater interception mechanisms (e.g., interception boreholes, trenches, reactive barriers).

8.3 OPEN PIT

Open pit mining of the Kwatebala Hill ore deposit will expose waste rock and ore materials. Assuming that the pit will be dewatered in order to keep the mining face dry, the quality of pit water during the operational phase will be determined by the influx of groundwater, and seepage and runoff from the exposed ore and waste rock materials. Mine planning for the open pit should take into account the following:

- Exposed pit wall within the oxide zone is unlikely to generate acid rock drainage.
- The comparison against water quality reference guidelines presented in Section 7 has identified that pit water may contain sulfate, metals (e.g., copper, cobalt) and nitrate at concentrations exceeding project-defined water quality reference guidelines.
- If transition zone ore and/or sulfide ore is extracted from the deeper parts of the pit, the pit wall is expected to have a range of acid rock drainage potentials. Exposure of this material may therefore result in acidic discharges that contain metals and TDS in concentrations higher than predicted for pit wall consisting of oxide lithologies.

Based on the preliminary simulated operational and closure pit water qualities for the proposed Kwatebala open cast pit, the following recommendations are proposed for mine planning:

- Pit water quality should be monitored during and after operation.
- A pit water balance needs to be developed to evaluate potential impacts to water resources (i.e., groundwater and surface water). Depending on the findings of this assessment, identification and implementation of remedial activities may be required. The following are remedial activities that have been applied to pit lakes worldwide to improve their water quality prior to, during and/or after pit lake formation:

- Use of amendments (generally after formation of pit lake):
  - Use of organics to create a reducing hypolimnion and enhance bioremediation e.g., stimulate algal growth.
  - Alkaline materials (to increase pH).
- "Mining for closure":
  - Enhance proportion of non-reactive rock on pit face.
  - Minimize exposure of highly reactive material.
- Accelerate pit lake formation and flooding.

8.4 TAILINGS STORAGE FACILITY

The TSF has been designed as a “zero discharge” facility. As such, the TSF will be lined to prevent seepage to groundwater. The proposed liner system will consist of a geomembrane underlain by compacted in situ clayey silt. TSF supernatant will be evaporated, remain permanently in storage, be recycled to the plant for re-use or be treated to meet acceptable water standards prior to being discharged to the environment (Section E9). The closure plan for the TSF is discussed in Section D5. At closure, a waste rock cover will be placed over the tailings. An evaporative pool will be established at the topographical low. During most storm events, beach runoff and direct precipitation will be retained within the evaporative pool. A spillway will be constructed to facilitate controlled release of evaporative pond water during extreme storm events.

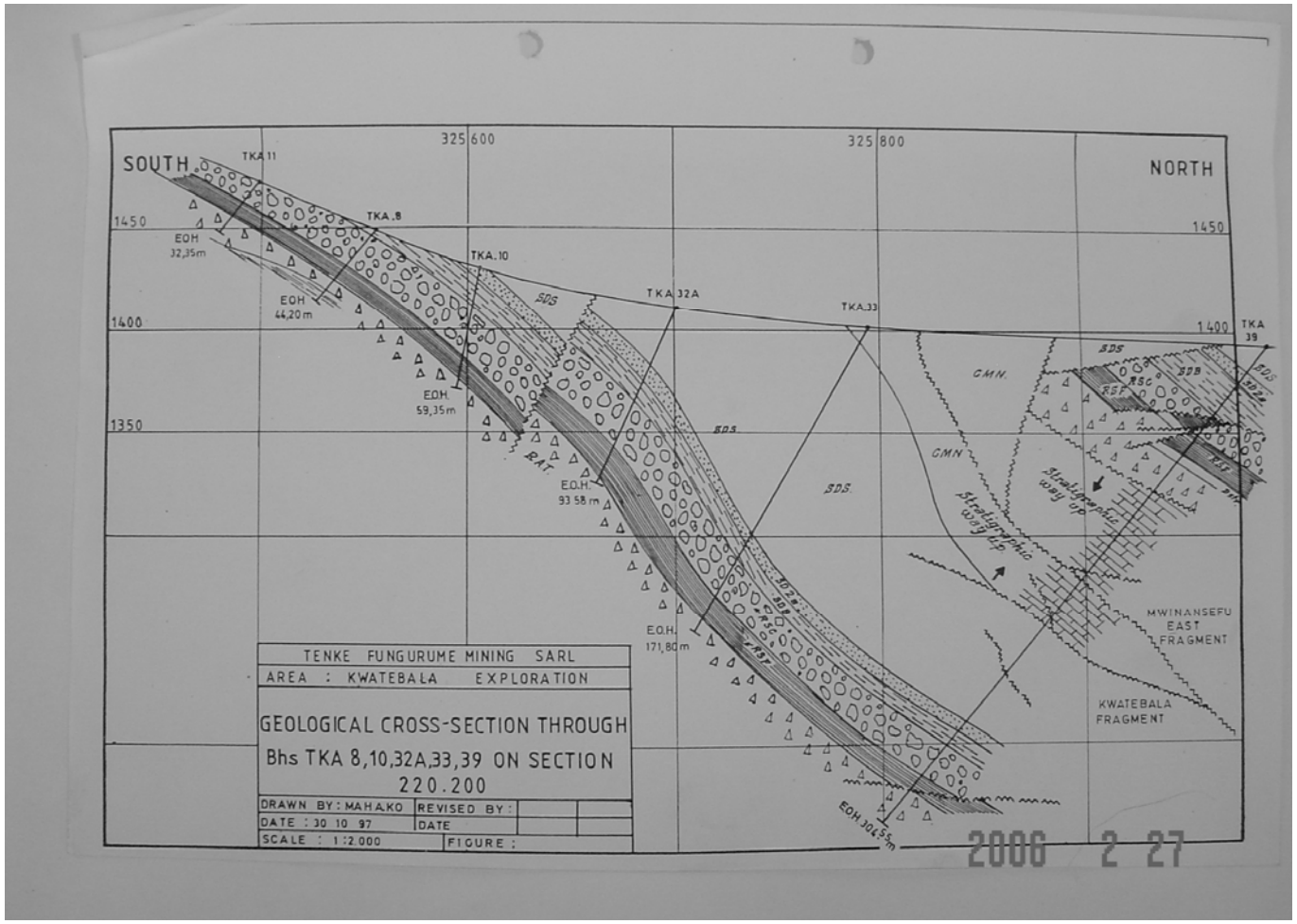
Despite the presence of a liner, a nominal amount of seepage should be expected. Similarly, contingency measures need to be in place in case of accidental discharges of tailings solids/supernatant outside of the tailings storage facility. The geochemical characteristics of tailings solids, seepage and supernatant are as follows:

- The tailings solids resulting from processing of oxide ore are unlikely to generate acid rock drainage.
- The comparison against water quality reference guidelines presented in Section 7 has identified that tailings seepage and supernatant may contain sulfate and metals (e.g., arsenic, copper, cobalt) at concentrations exceeding project-defined water quality reference guidelines.
- If transition zone ore and/or sulfide ore is extracted from the deeper parts of the pit, the associated tailings may have a range of acid rock drainage potentials. Due to use of liming to enhance pH, acidic conditions within the TSF may be preventable. However, the lime dosing should be re-evaluated if ore other than from the oxide zone is processed.

Based on the characteristics for the tailings solid and supernatant/seepage, the following recommendations for mine planning are proposed:

- An ongoing water quality monitoring program is required to identify environmental risks during operation of the TSF and post closure.
- Collection and proper handling of tailings water may be needed if potential impacts to water resources are identified. Such measures may include, but not be limited to:
  - Active or passive water treatment (e.g., wetland).
  - Retention and use in the mine water circuit.
  - Retention and controlled release.
  - Groundwater interception mechanisms (e.g., interception boreholes, trenches, reactive barriers).

FIGURES

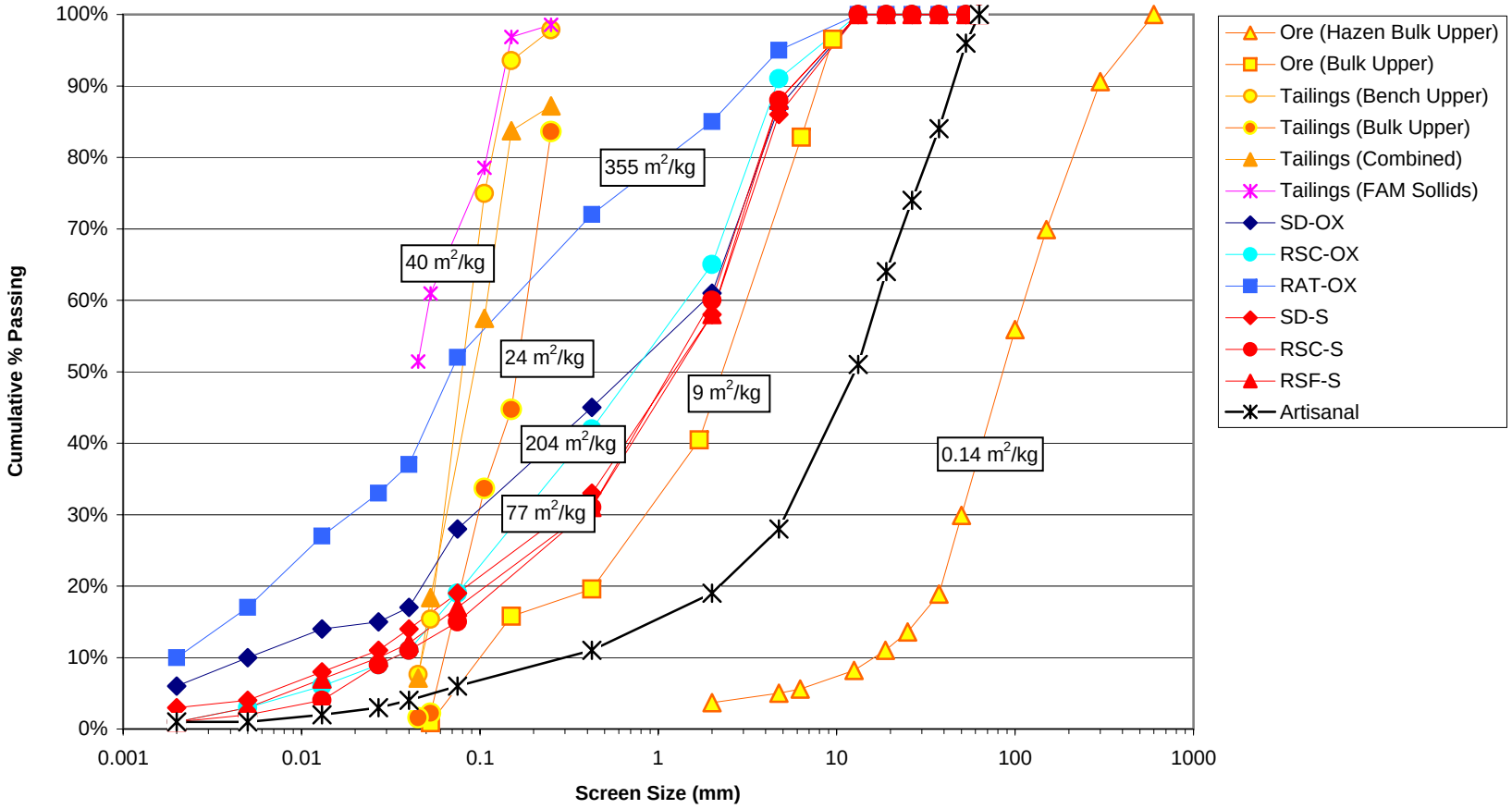


Golder Associates

Deeper Waste Rock Sample Selection - Cross Section Example

Tenke Fungurume Mining S.A.R.L. (TFM)

DRAWN	na	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	KG	SCALE	na	DWG. NO.	
REVIEWED	NB	FILE NO.	Tenke - Pit Figures (Mar 07).xls	FIGURE NO.	**4.2-1**



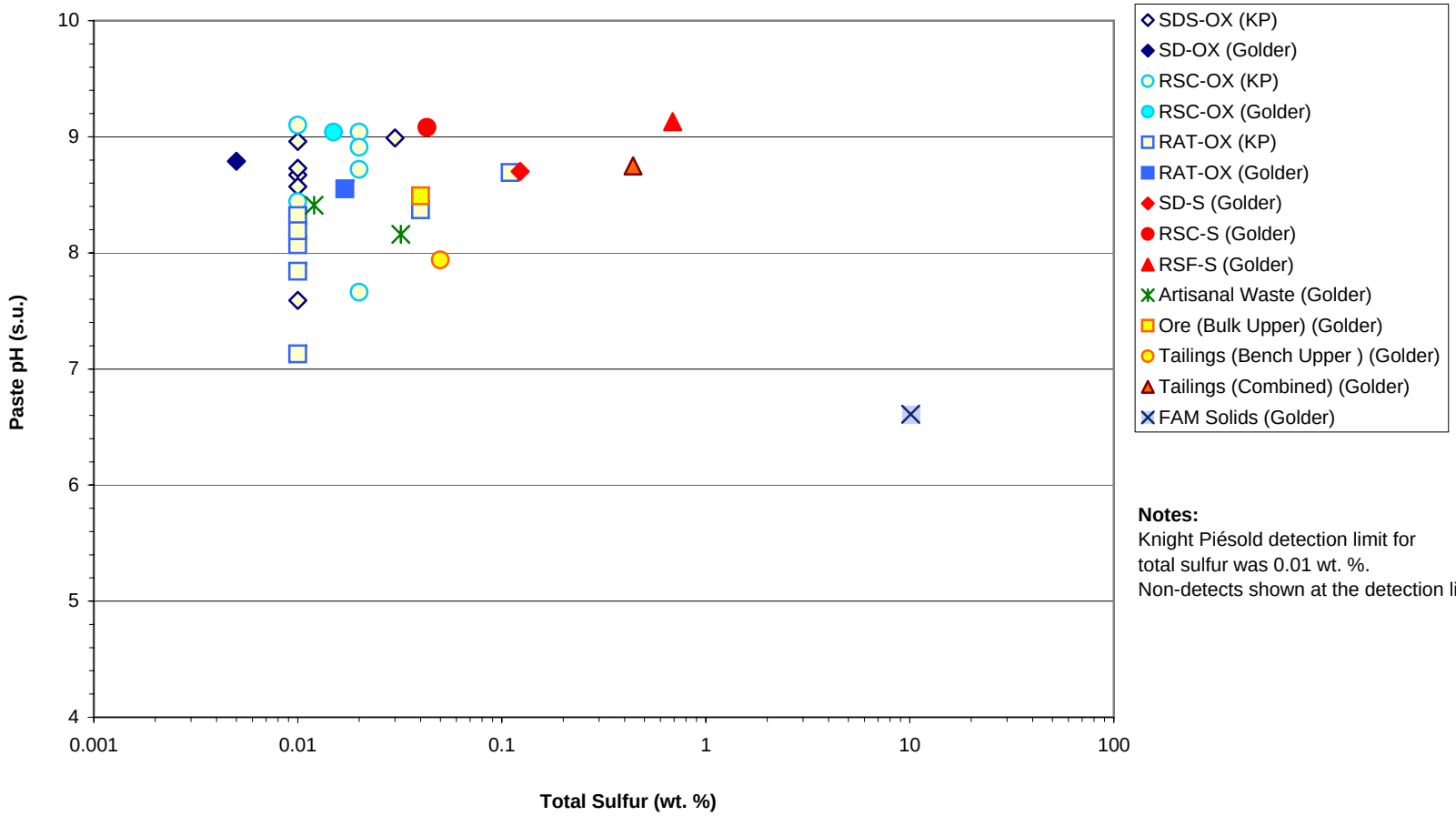
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Sample Particle Size Distributions

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Particle Size (Mar 07).xls	FIGURE NO.	**5.1-1**



Notes:
Knight Piésold detection limit for total sulfur was 0.01 wt. %.
Non-detects shown at the detection limit.

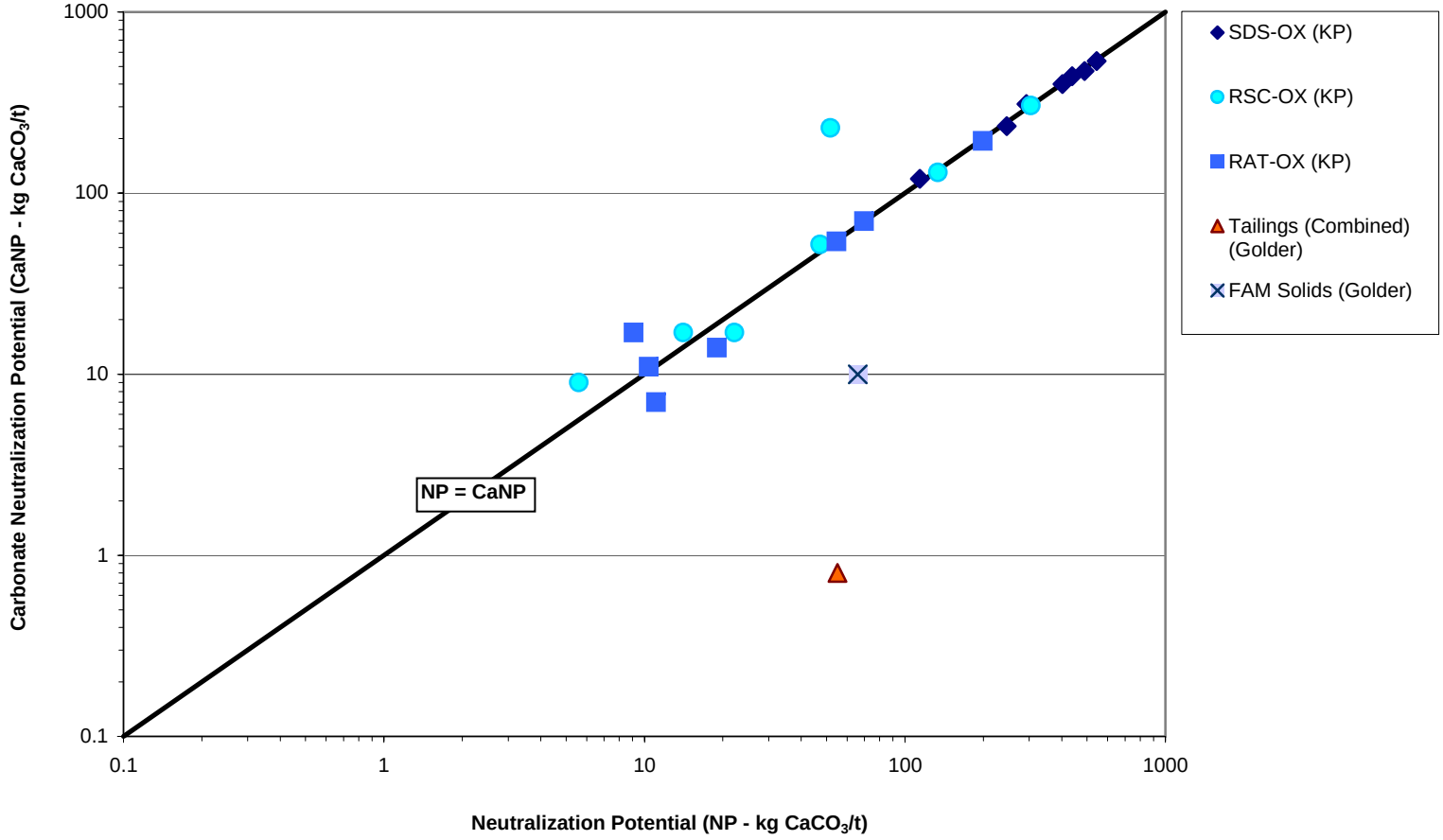
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

ABA Results - Total Sulfur vs. Paste pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - ABA Figures (Mar 07).xls	FIGURE NO.	**5.3-1**



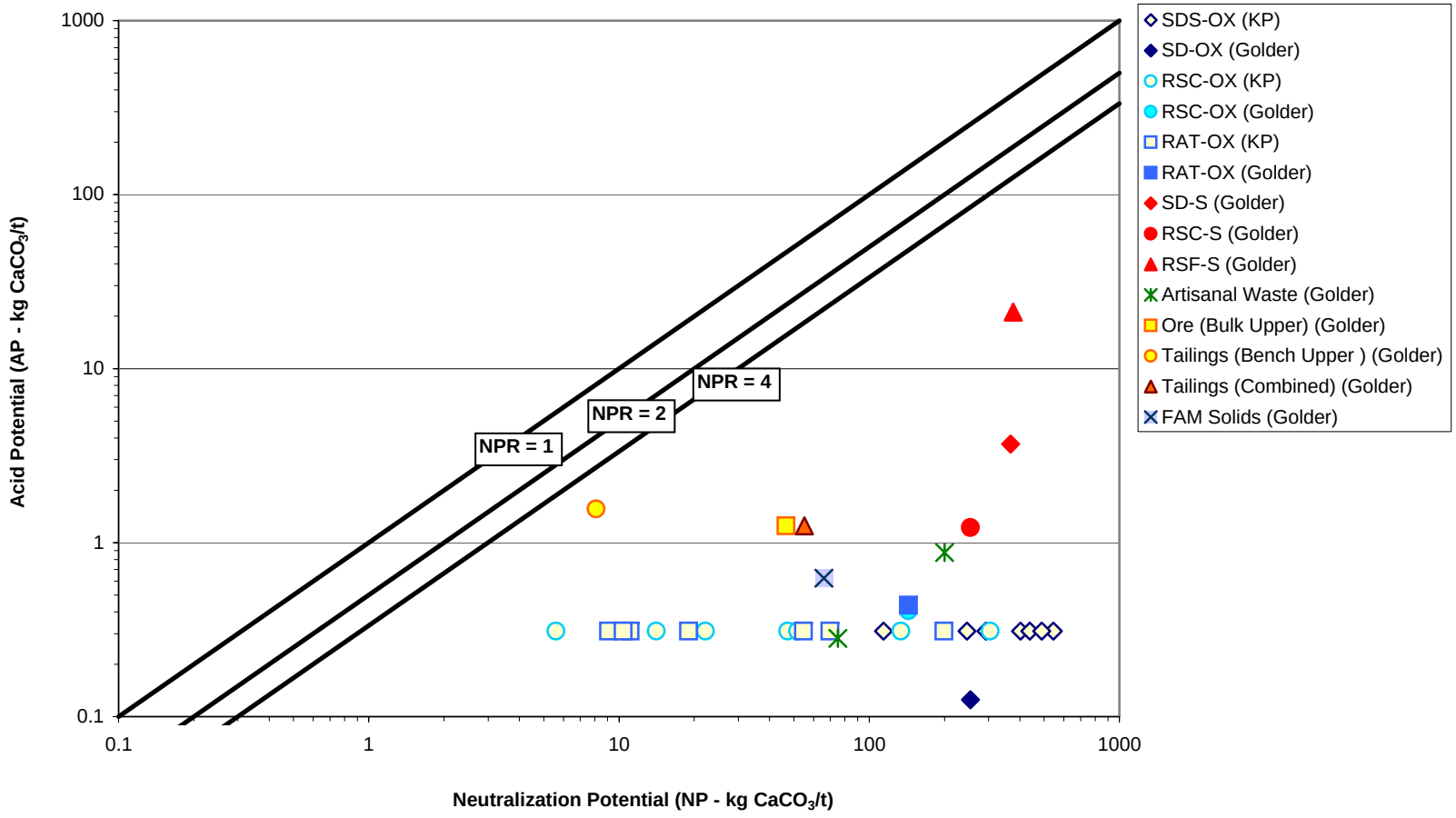
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

ABA Results - Neutralization Potential (NP) vs. Carbonate Neutralization Potential (CaNP)

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - ABA Figures (Mar 07).xls	FIGURE NO.	5.3-2



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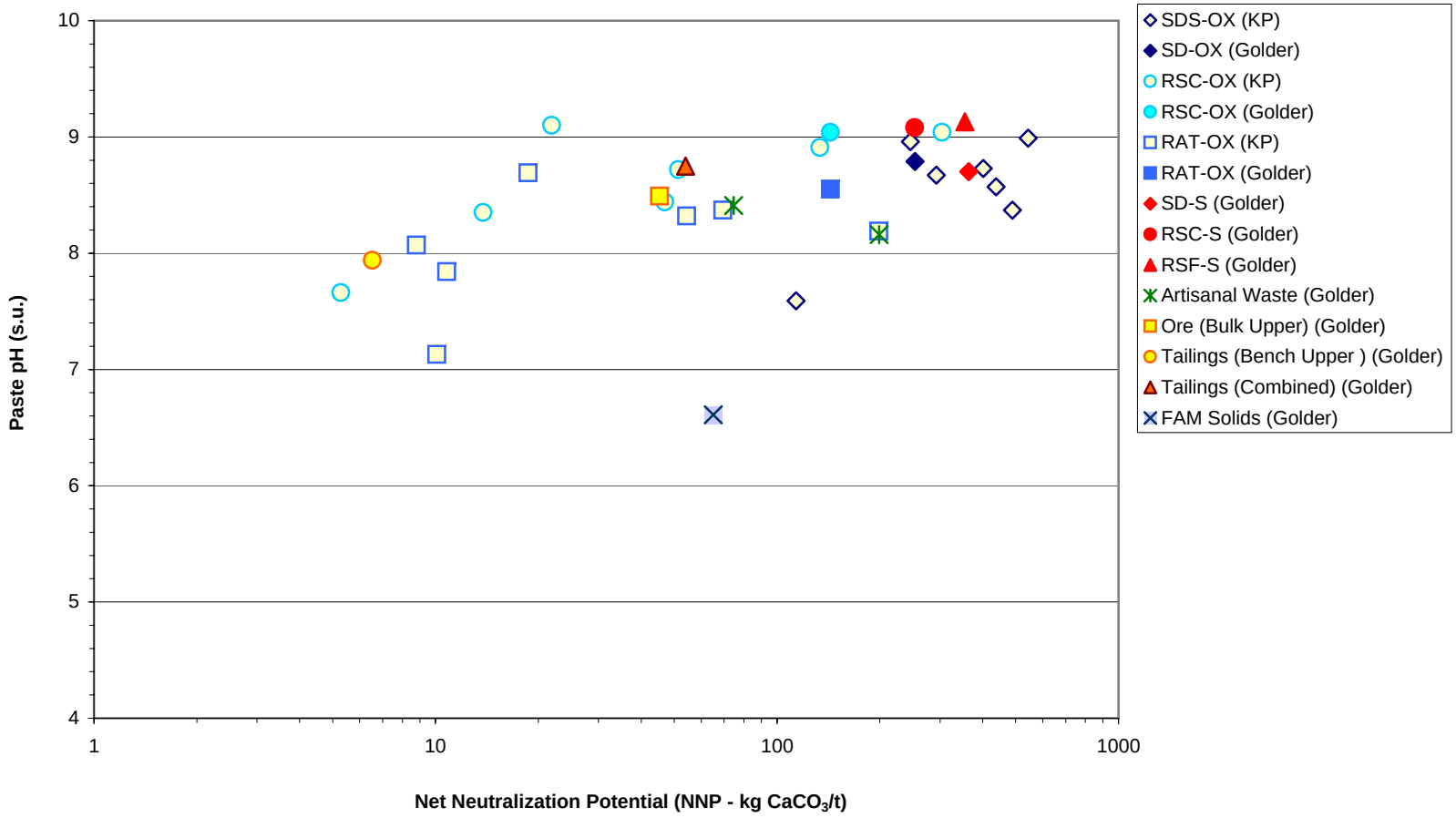
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

ABA Results - Neutralization Potential (NP) vs. Acid Potential (AP)

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - ABA Figures (Mar 07).xls	FIGURE NO.	5.3-3



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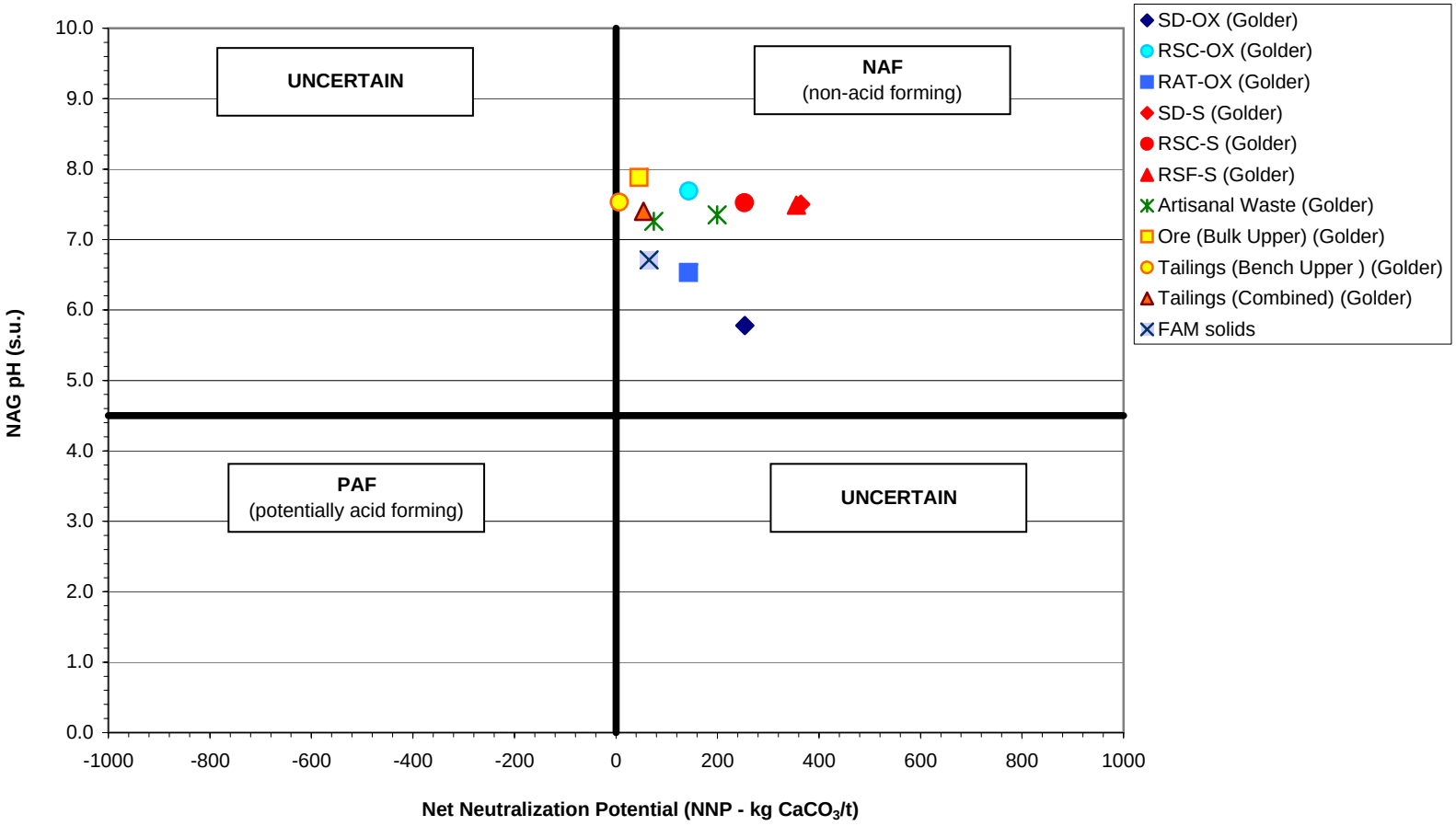
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

ABA Results - Net Neutralization Potential (NNP) vs. Paste pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - ABA Figures (Mar 07).xls	FIGURE NO.	5.3-4



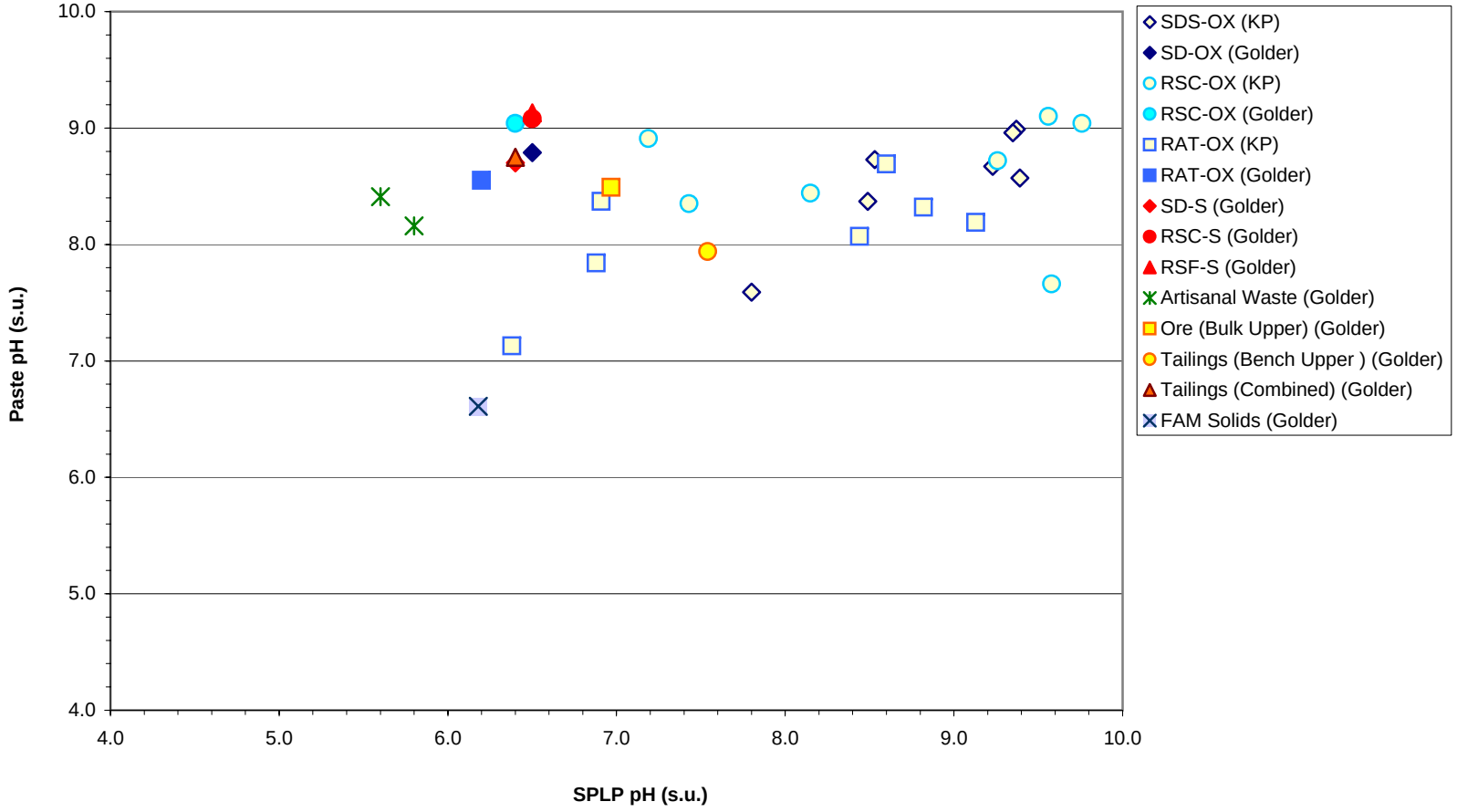
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

ABA Results - Net Neutralization Potential (NNP) vs. NAG pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - ABA Figures (Mar 07).xls	FIGURE NO.	5.3-5



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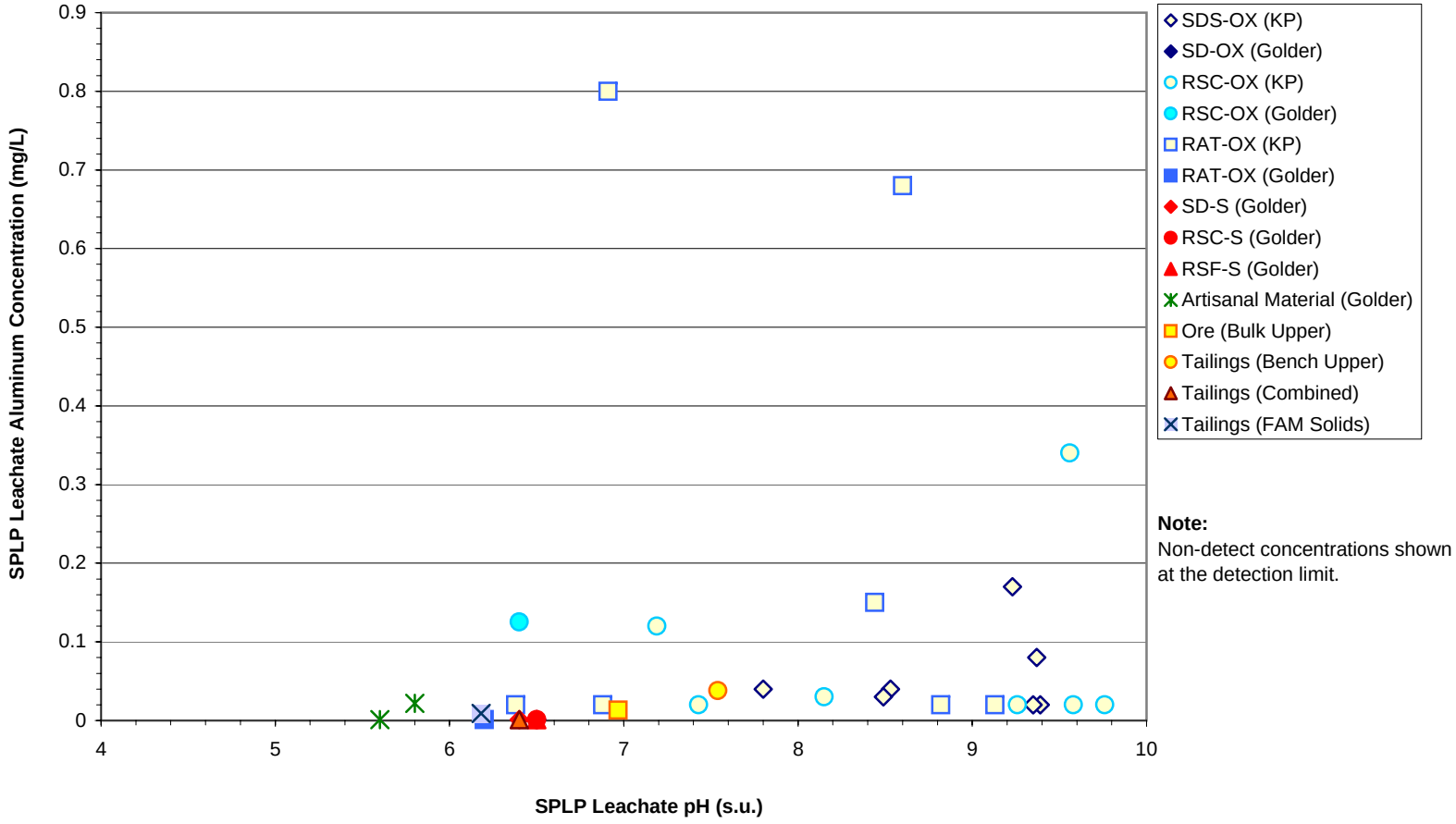
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Waste Rock Paste pH vs. SPLP pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - ABA Figures (Mar 07).xls	FIGURE NO.	**5.4-1**



Note:
Non-detect concentrations shown at the detection limit.

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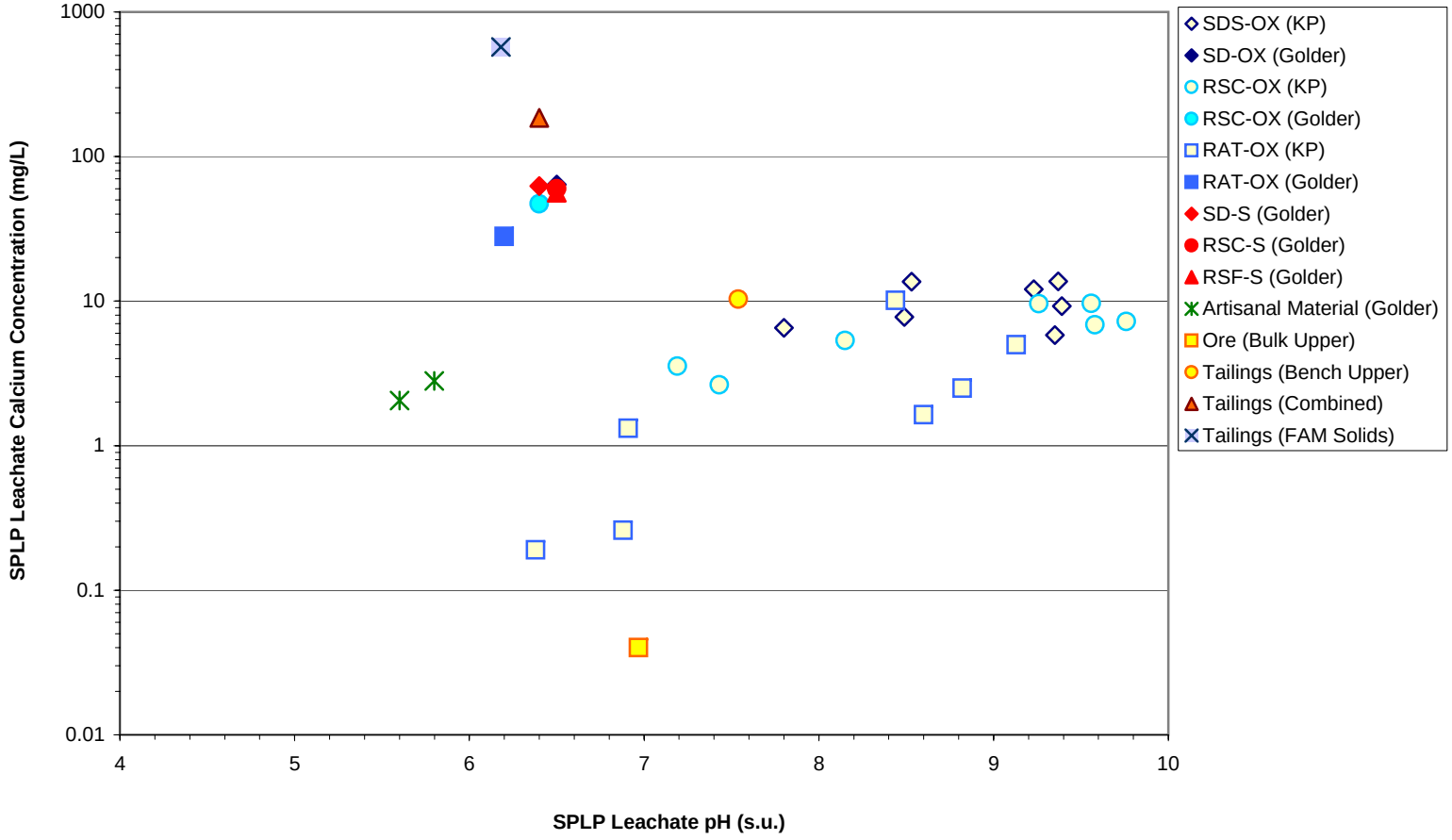
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Aluminum vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-2**



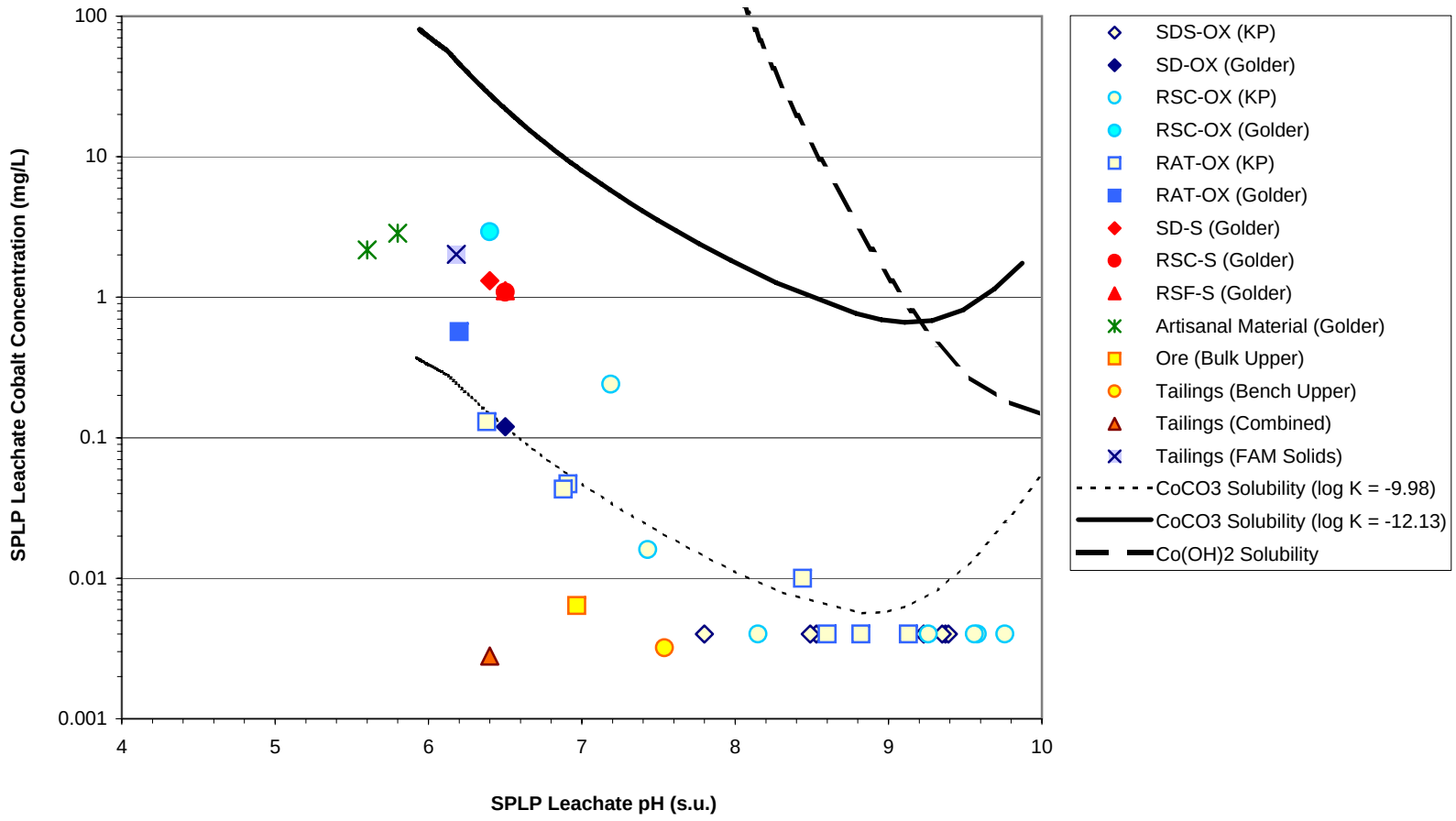
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Calcium vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	5.4-3



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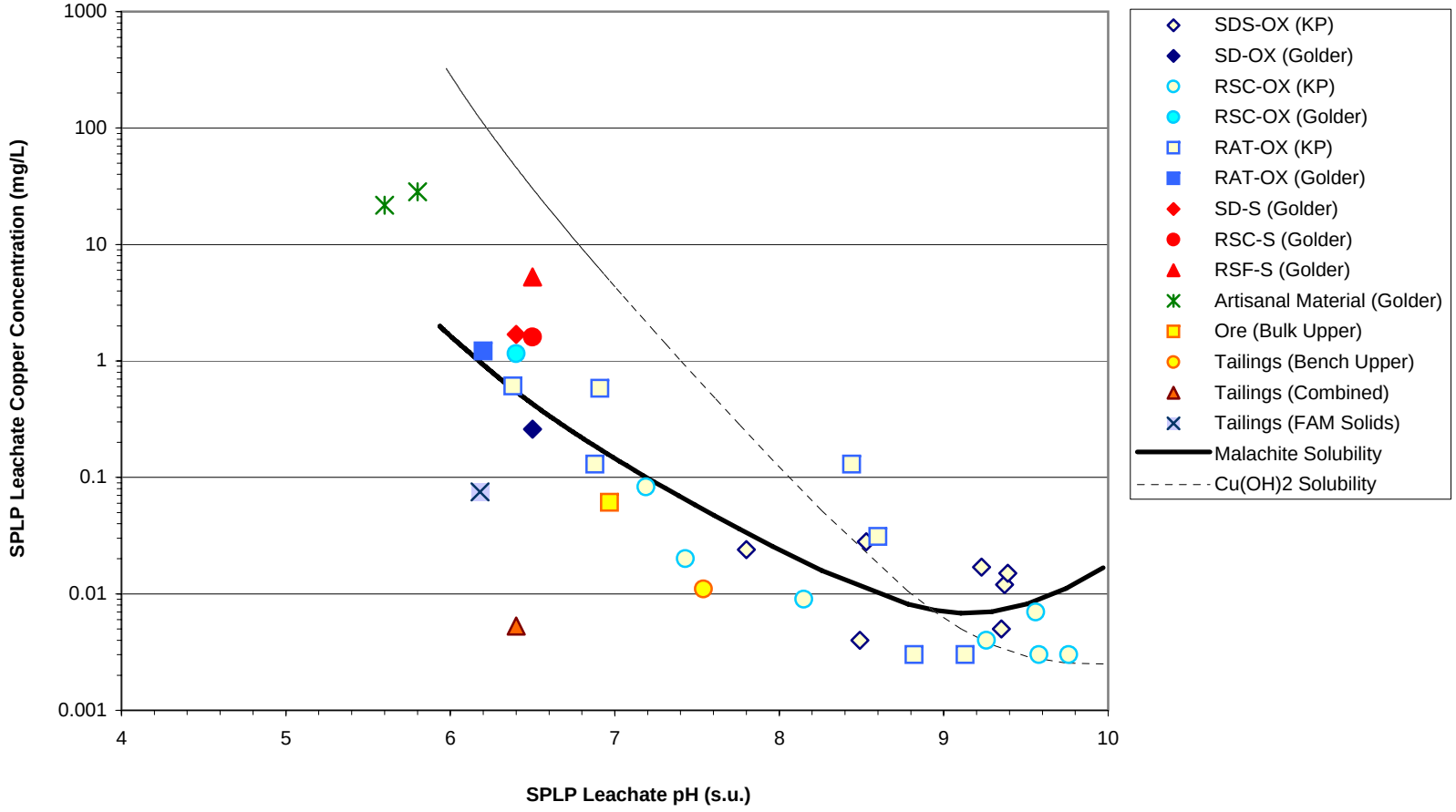
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Cobalt vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-4**



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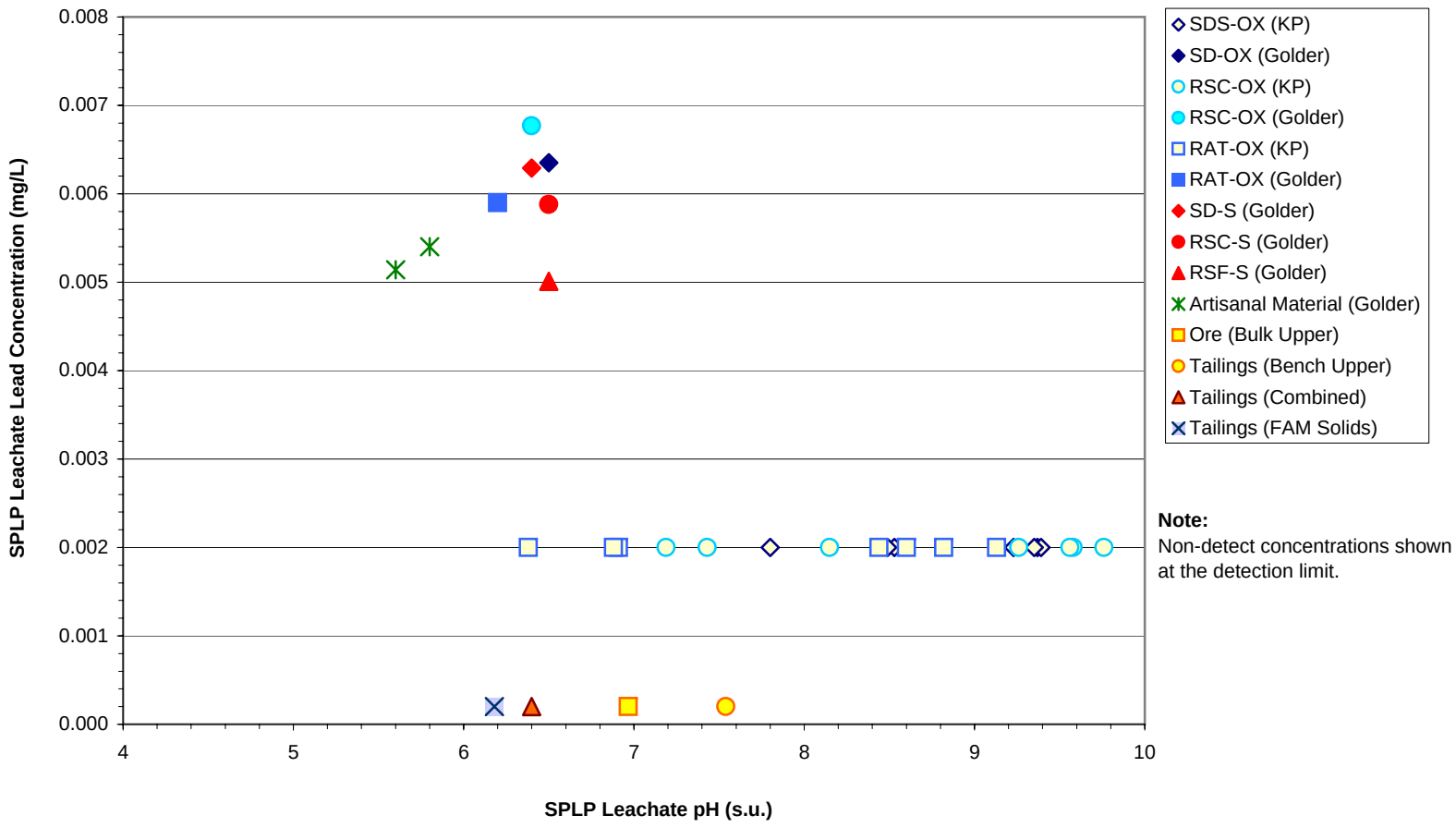
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Copper vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	5.4-5



Note:
Non-detect concentrations shown at the detection limit.

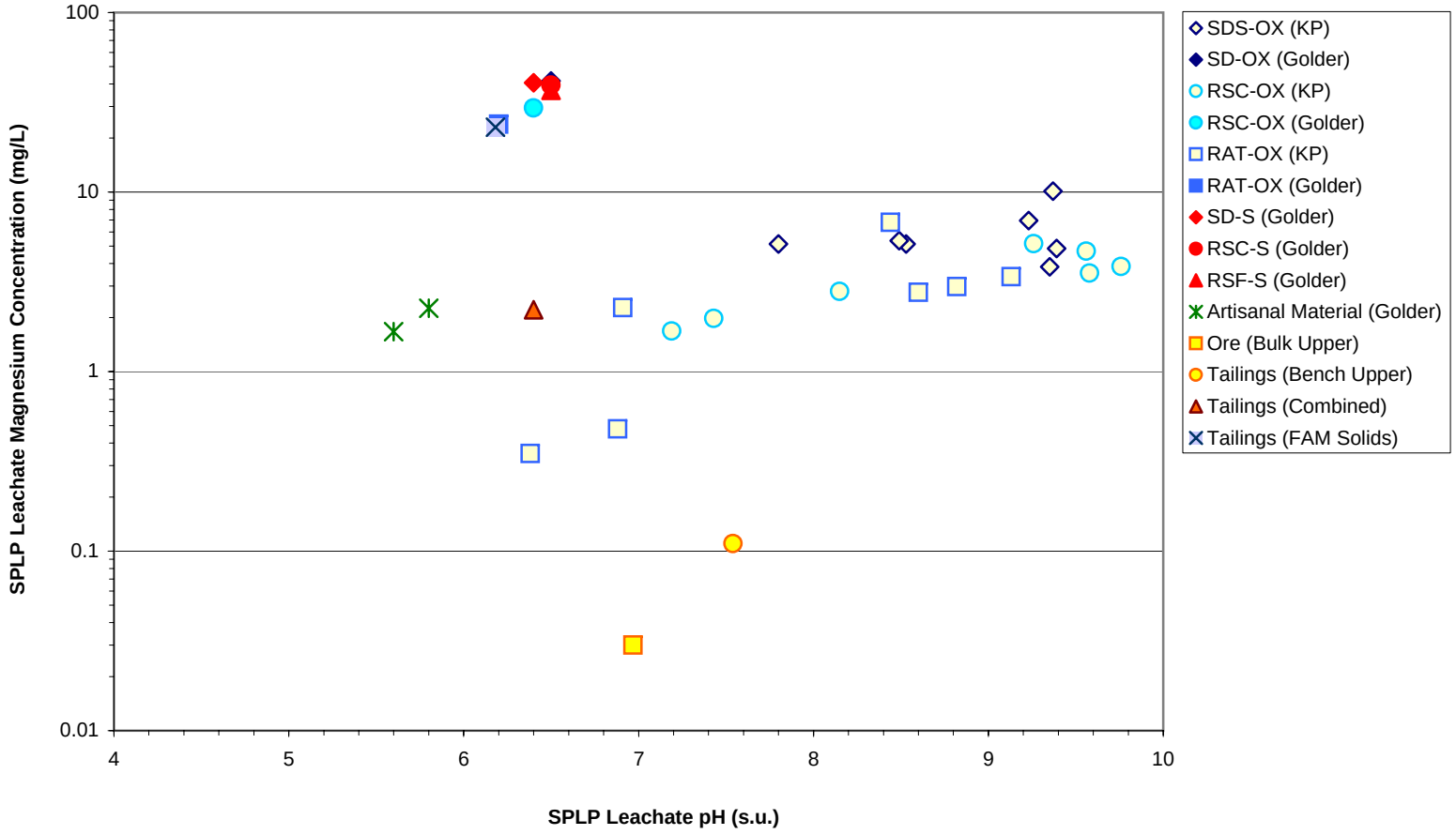
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Lead vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-6**



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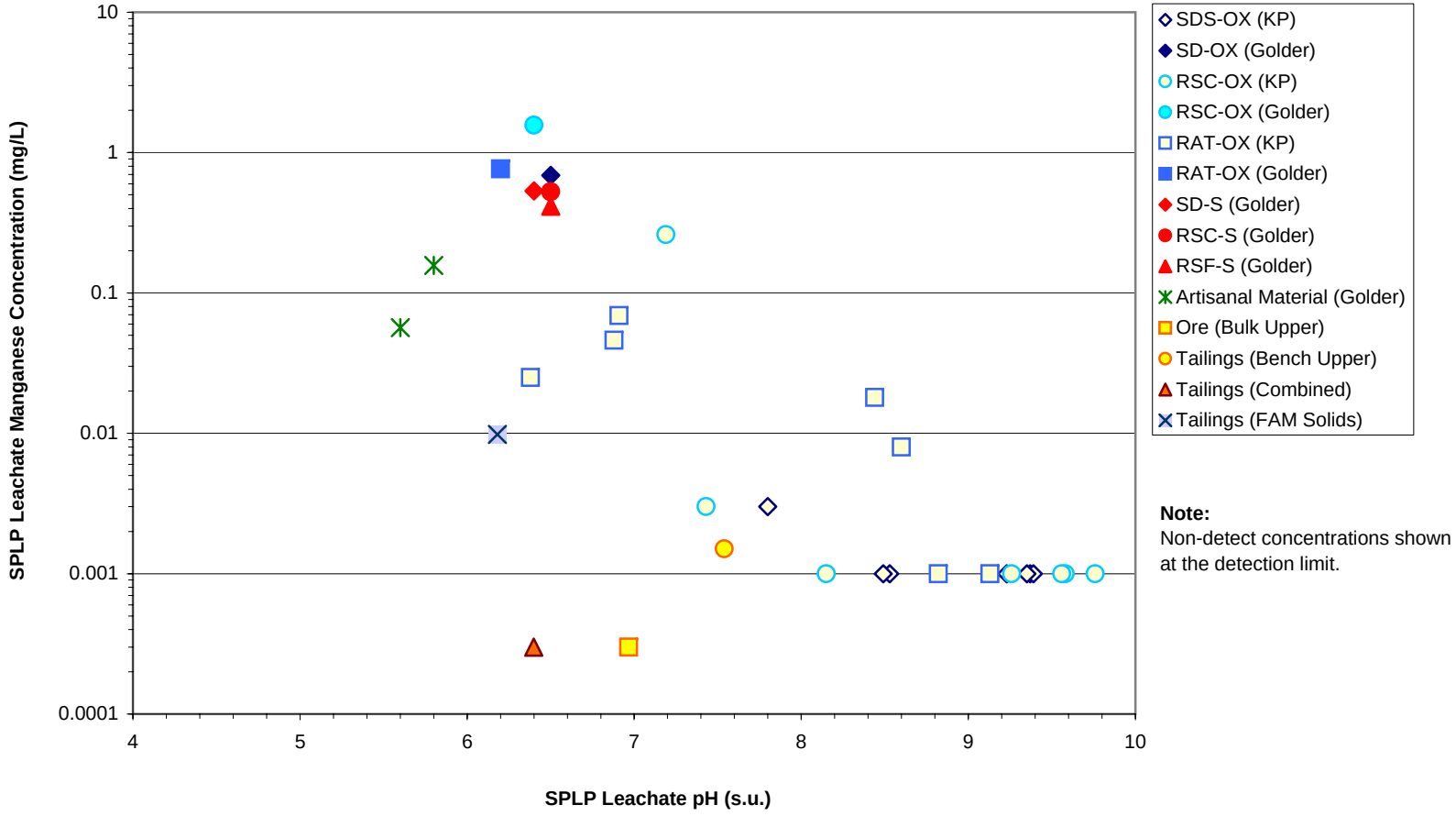
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Magnesium vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	5.4-7



Note:
Non-detect concentrations shown at the detection limit.

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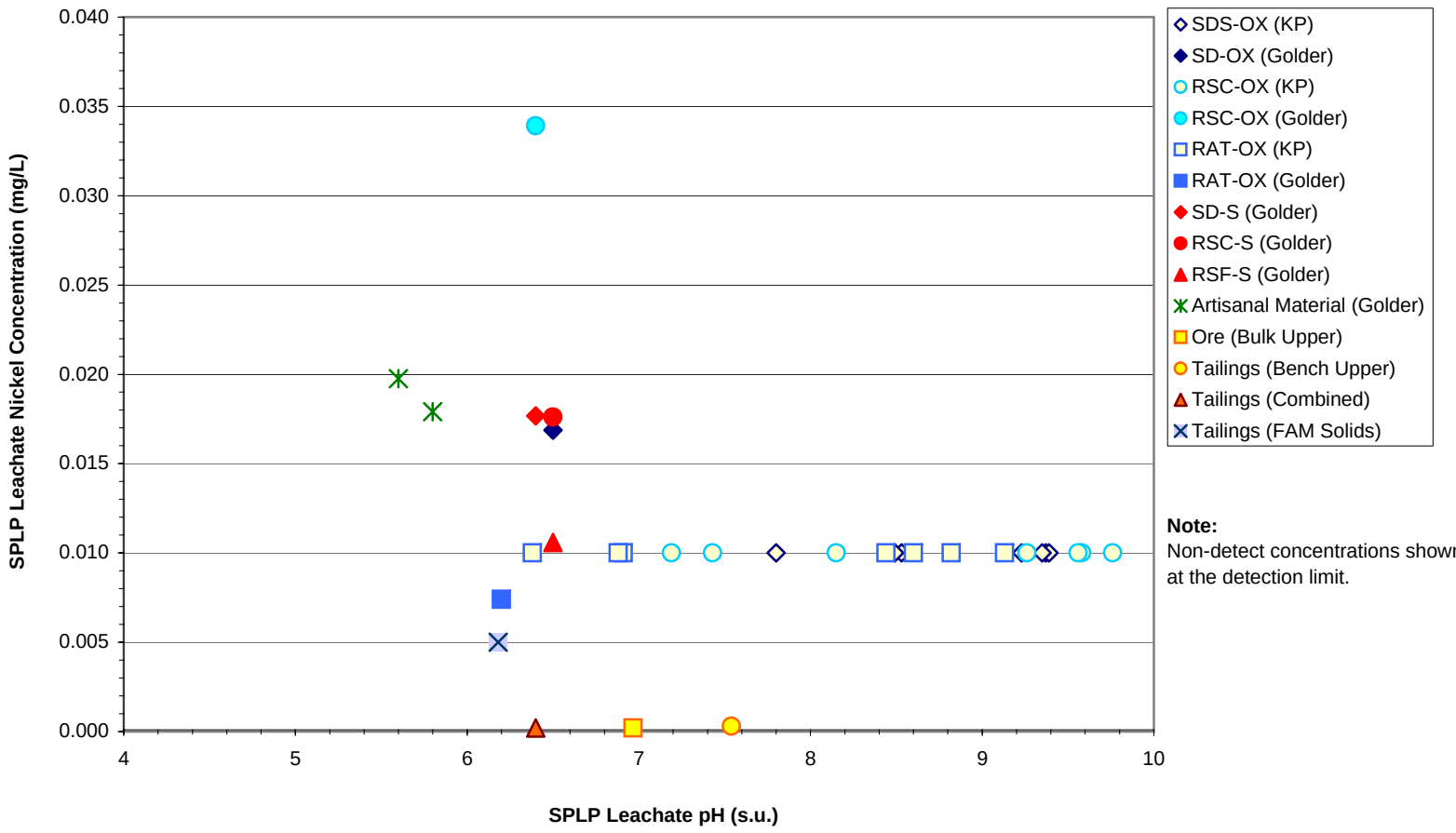
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Manganese vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-8**



Note:
Non-detect concentrations shown at the detection limit.

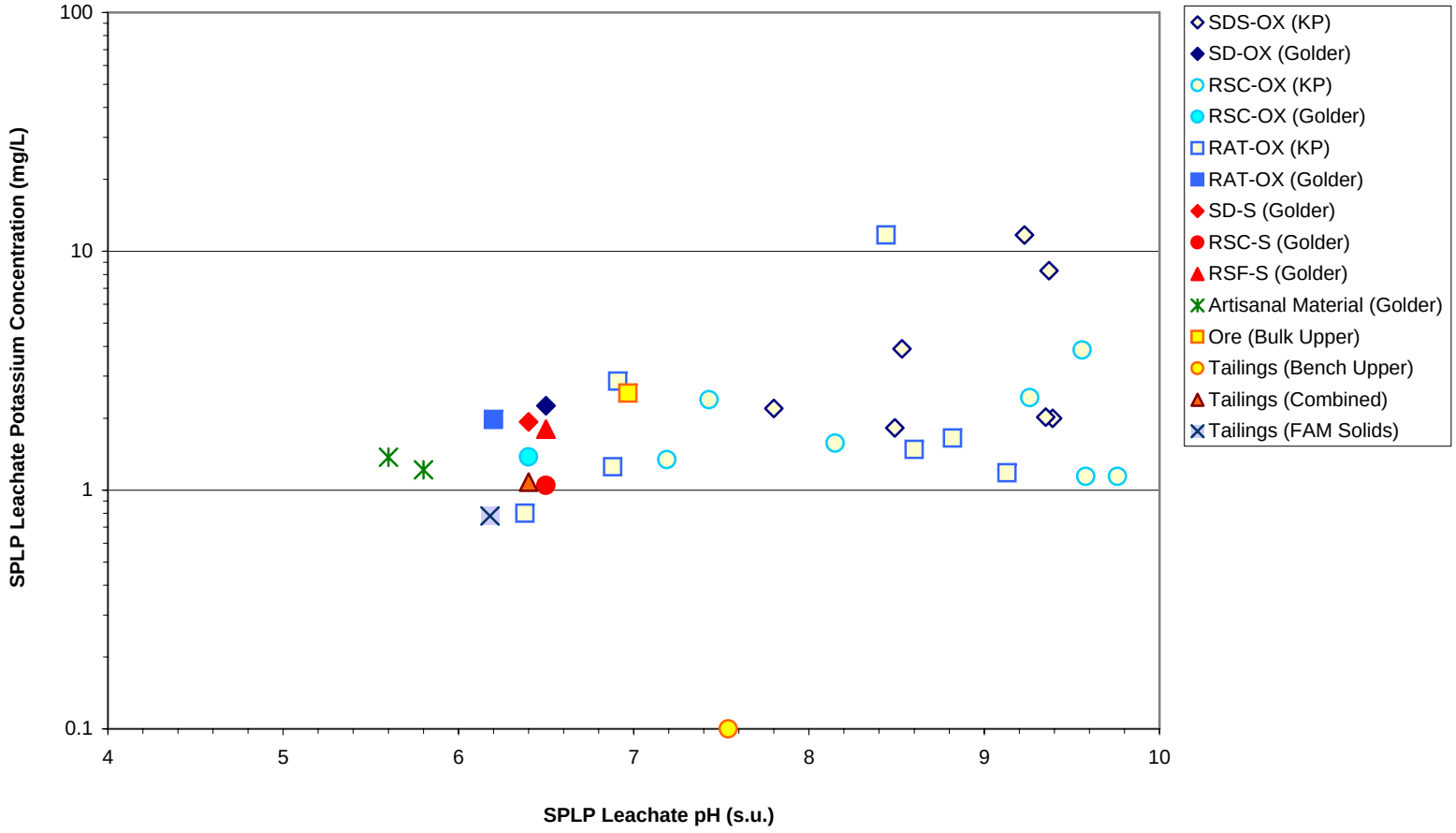
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Nickel vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-9**



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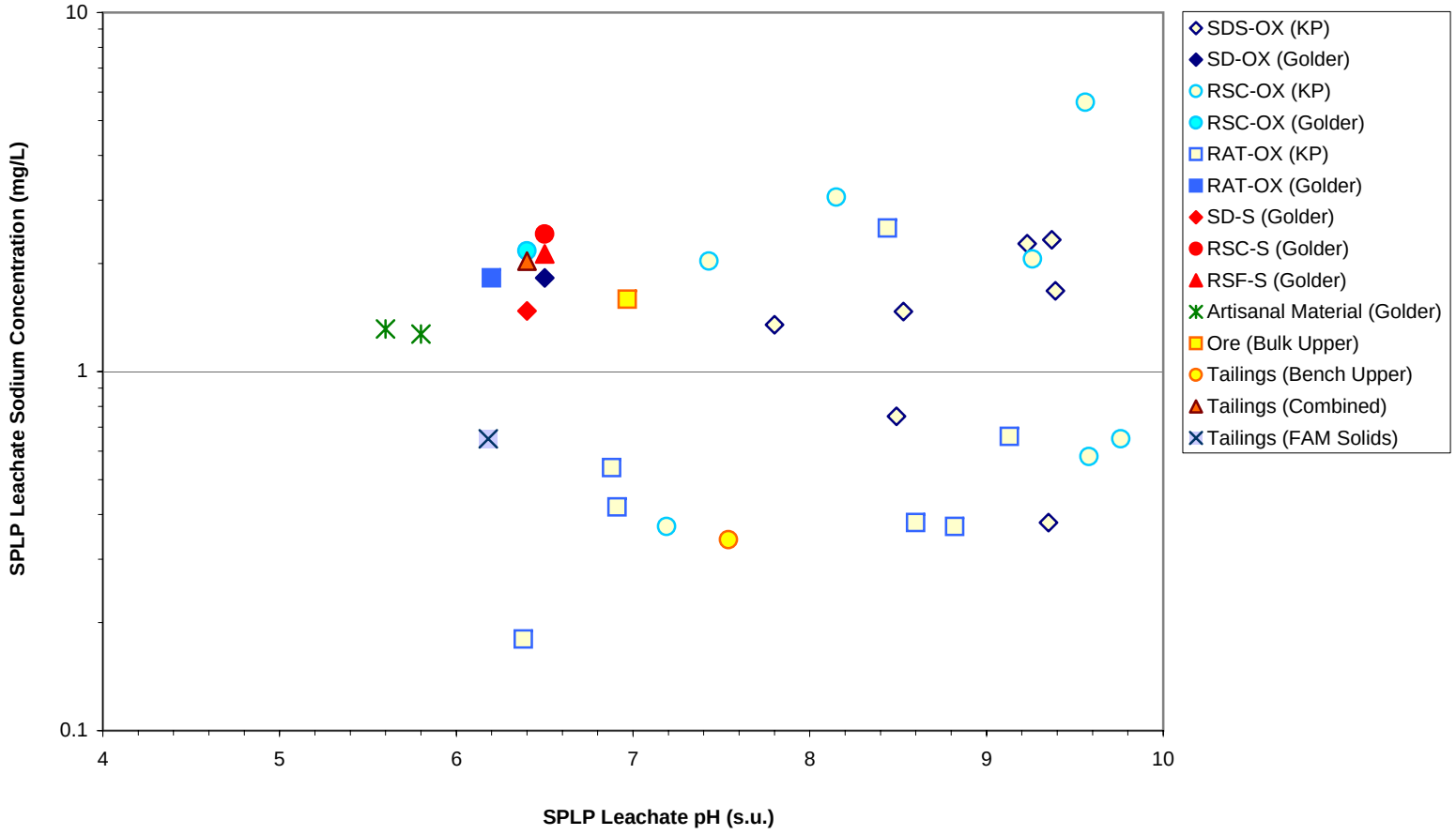
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Potassium vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	5.4-10



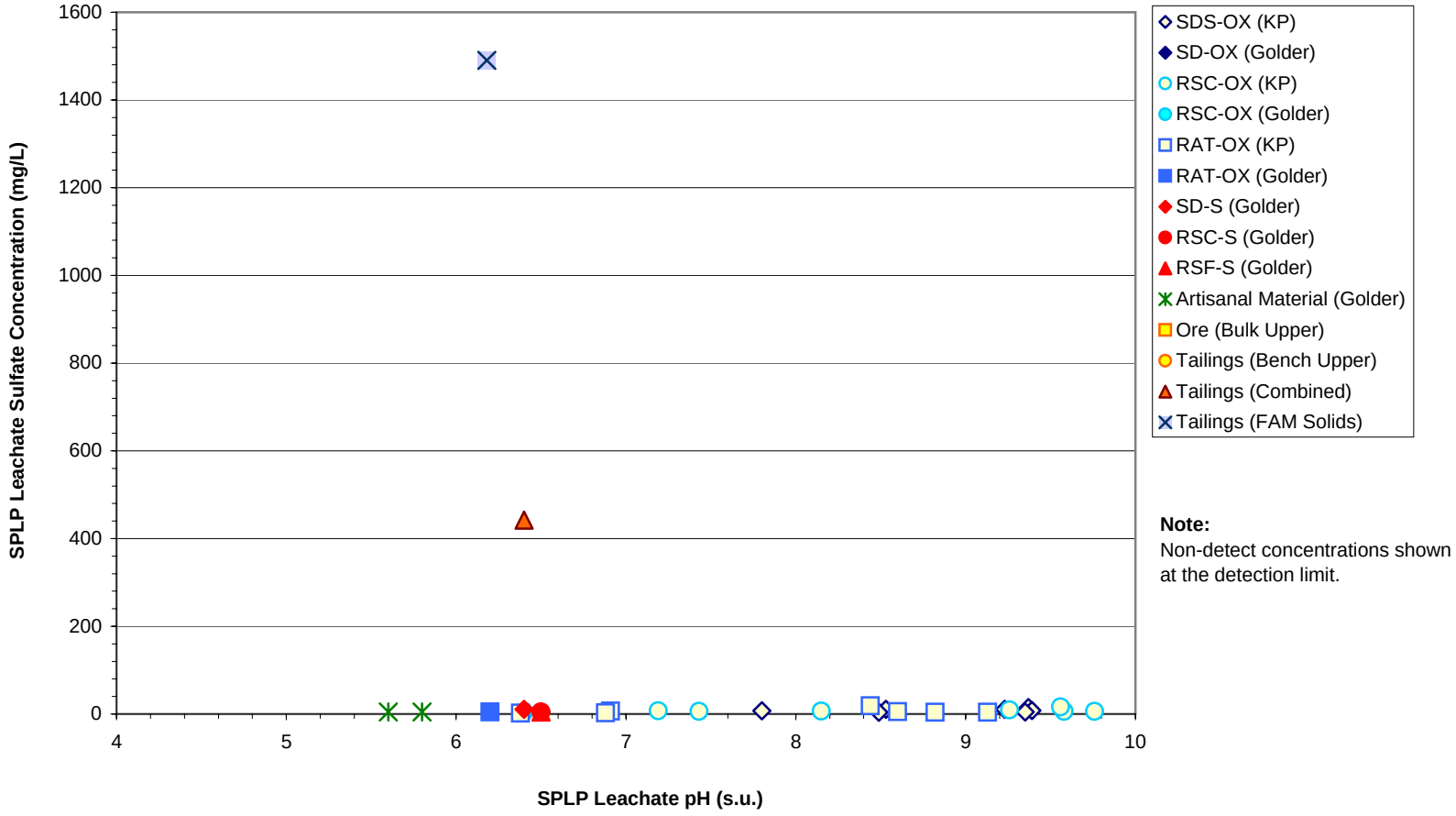
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Sodium vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	5.4-11



Note:
Non-detect concentrations shown at the detection limit.

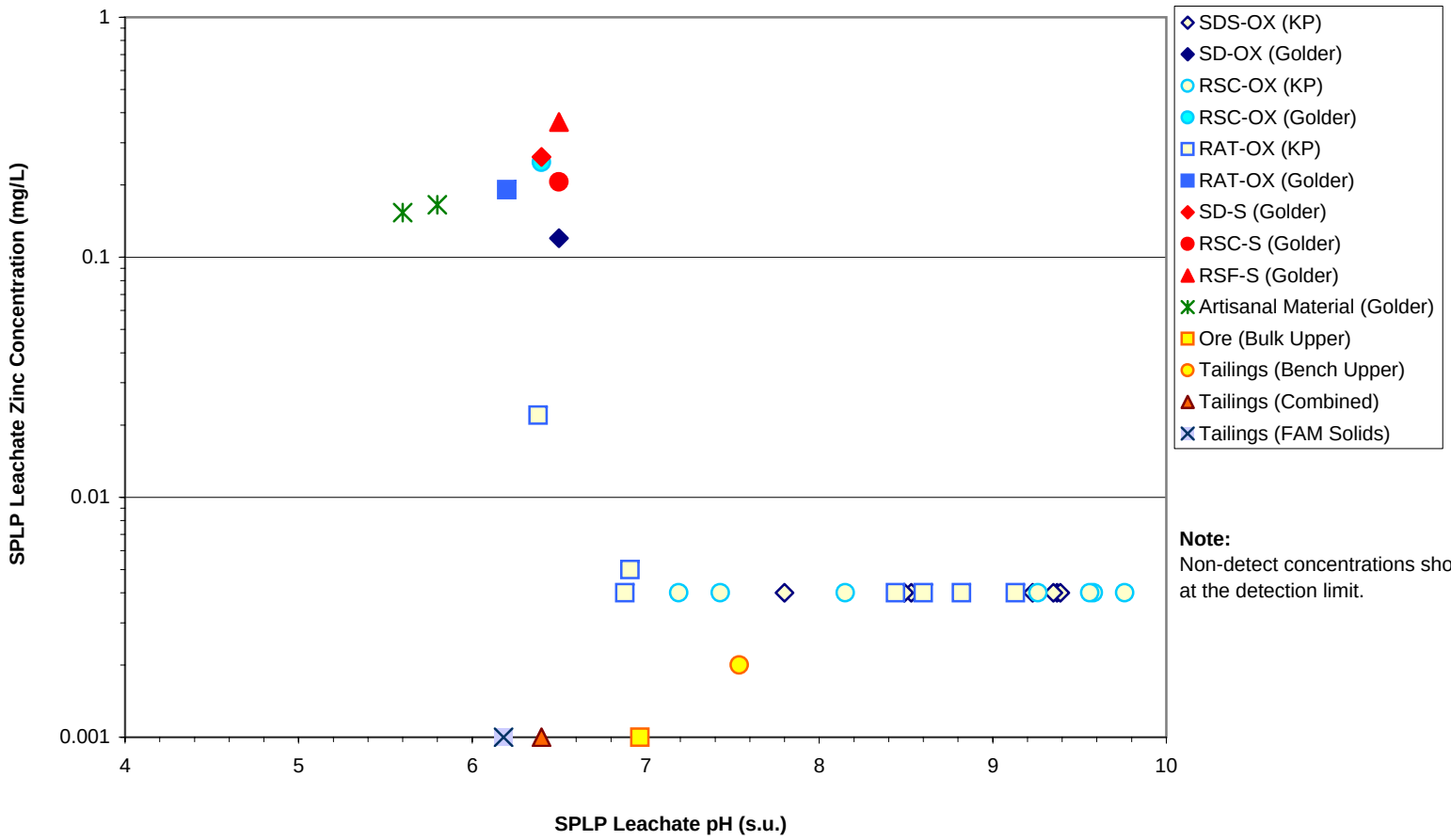
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Sulfate vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-12**



Note:
Non-detect concentrations shown at the detection limit.

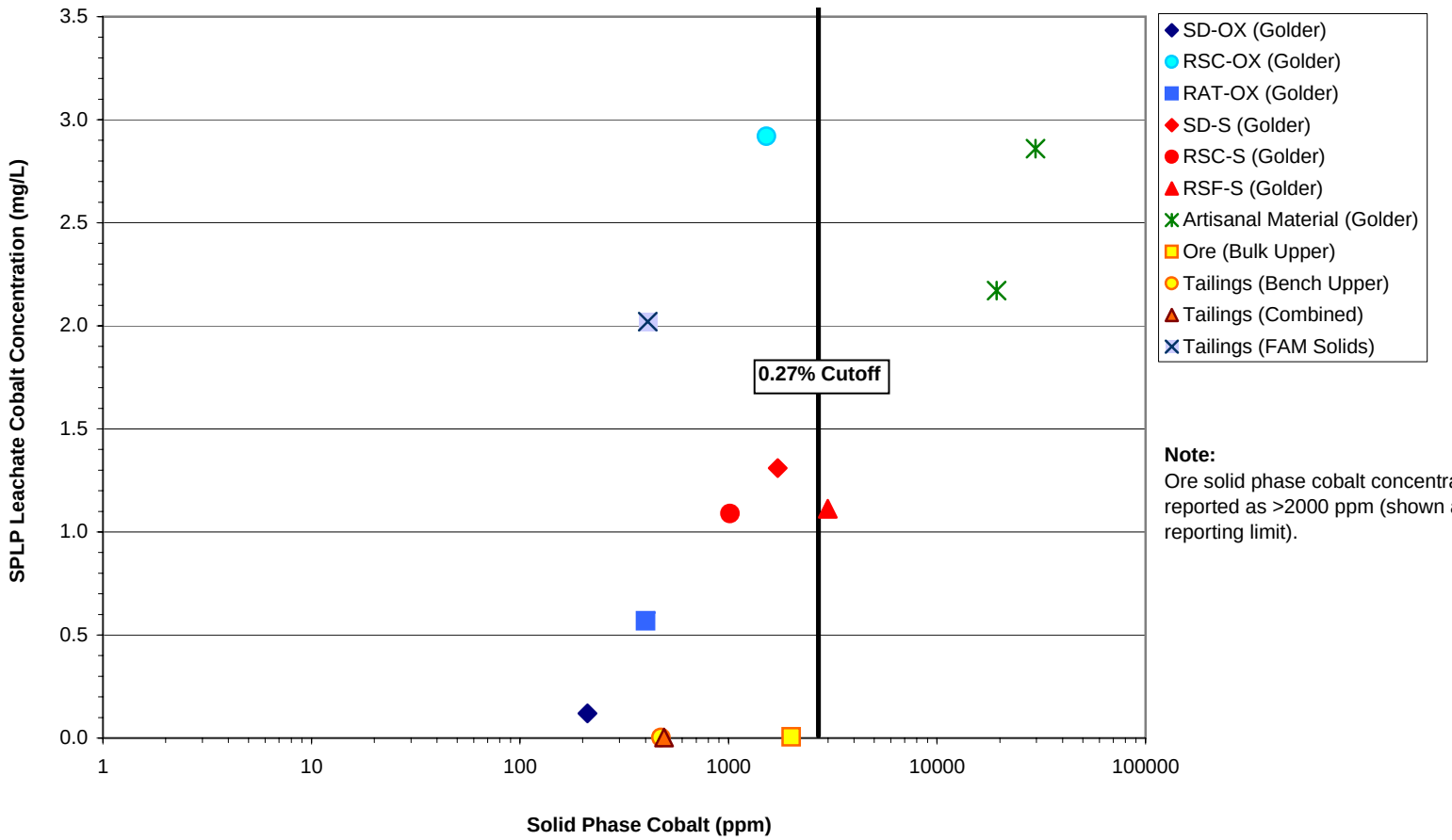
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

SPLP Leachate Results - Zinc vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-13**



Note:
Ore solid phase cobalt concentration reported as >2000 ppm (shown at the reporting limit).

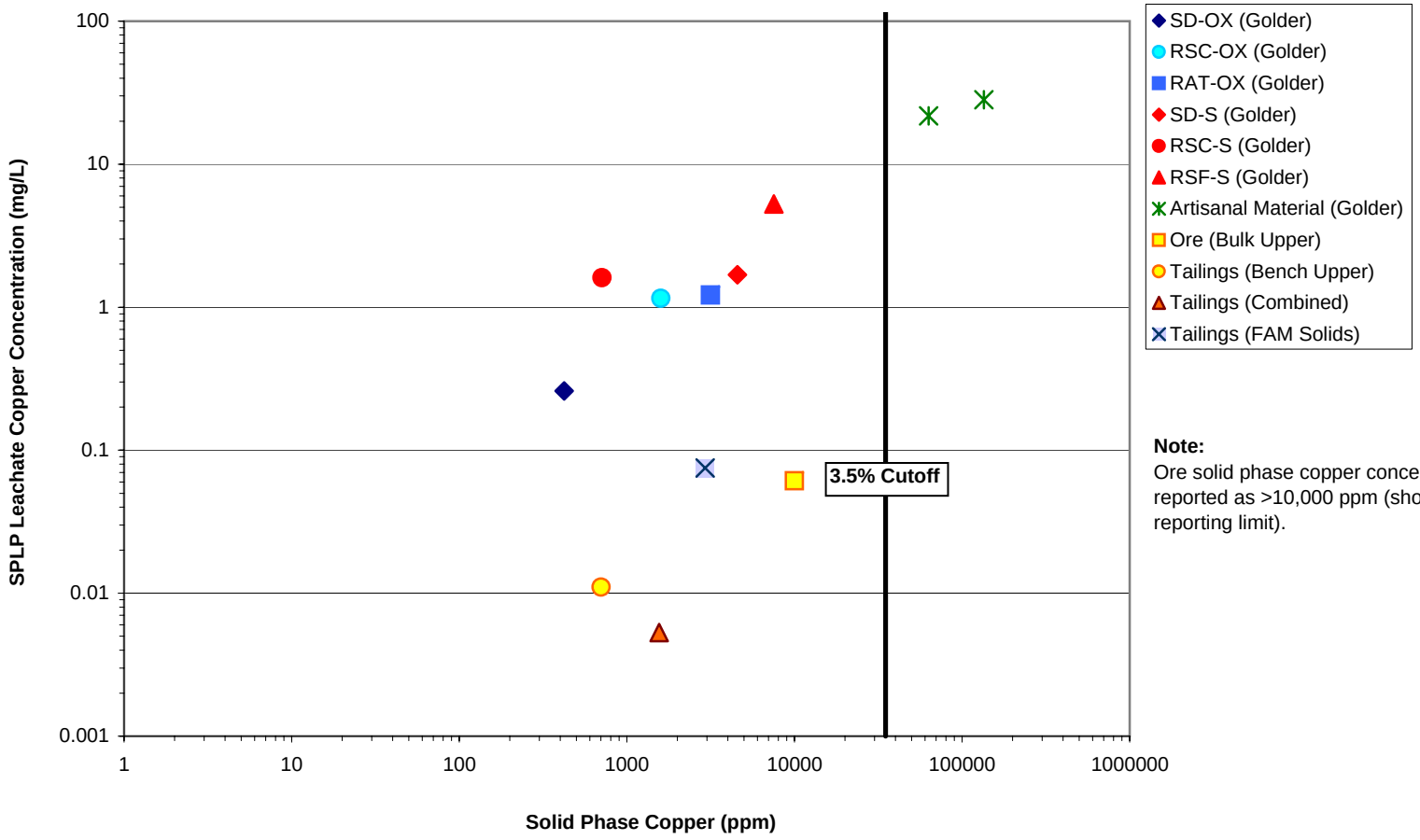
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Solid vs. SPLP Leachate Cobalt Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-14**



Note:
Ore solid phase copper concentration reported as >10,000 ppm (shown at the reporting limit).

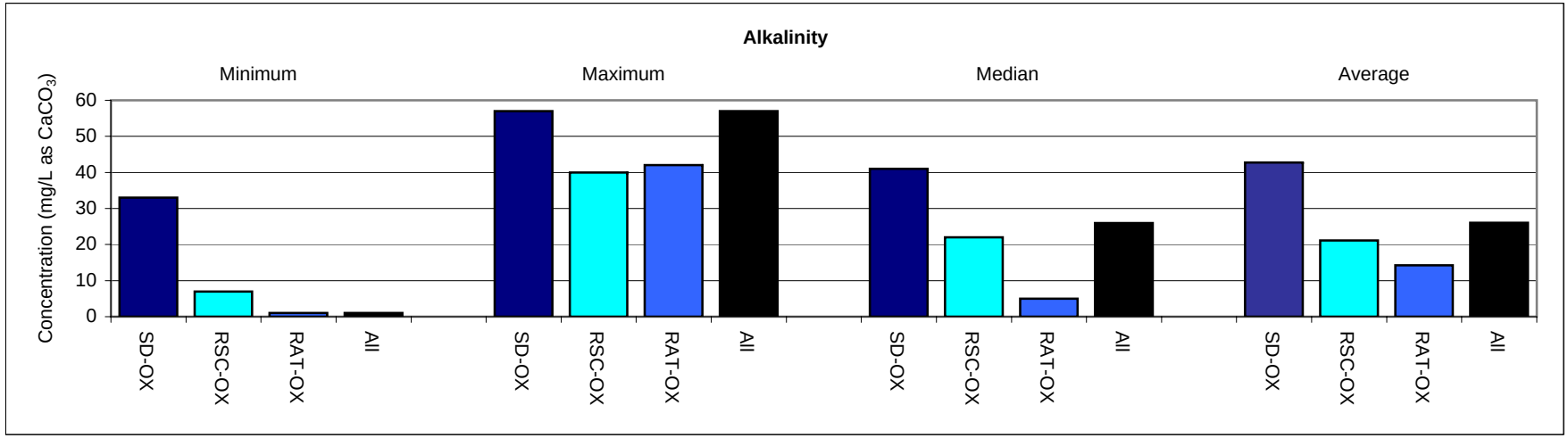
Golder Associates

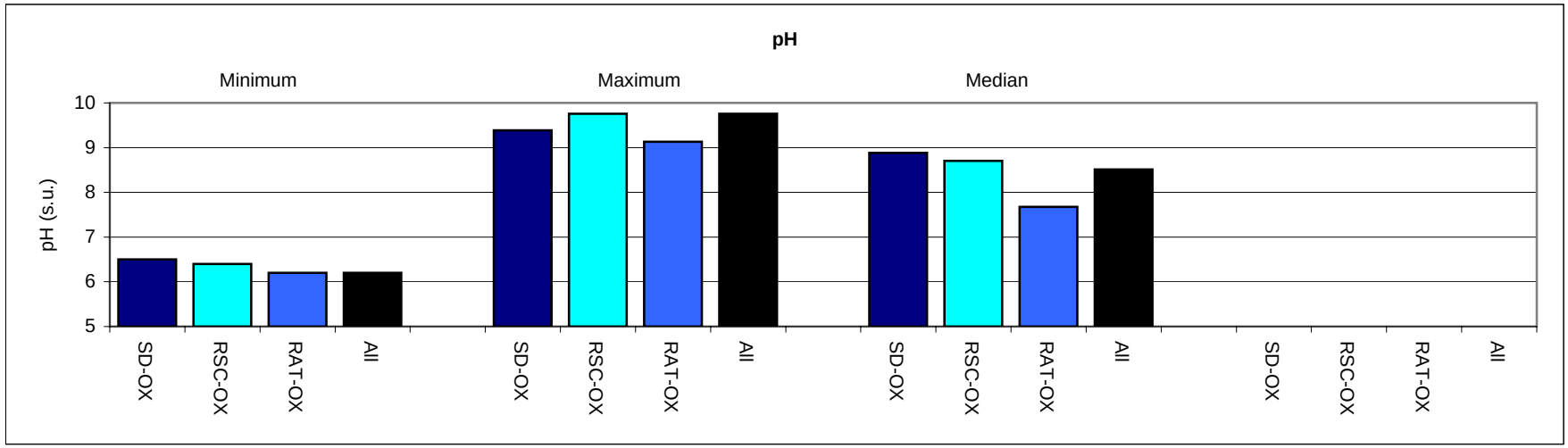
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Solid vs. SPLP Leachate Copper Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-15**





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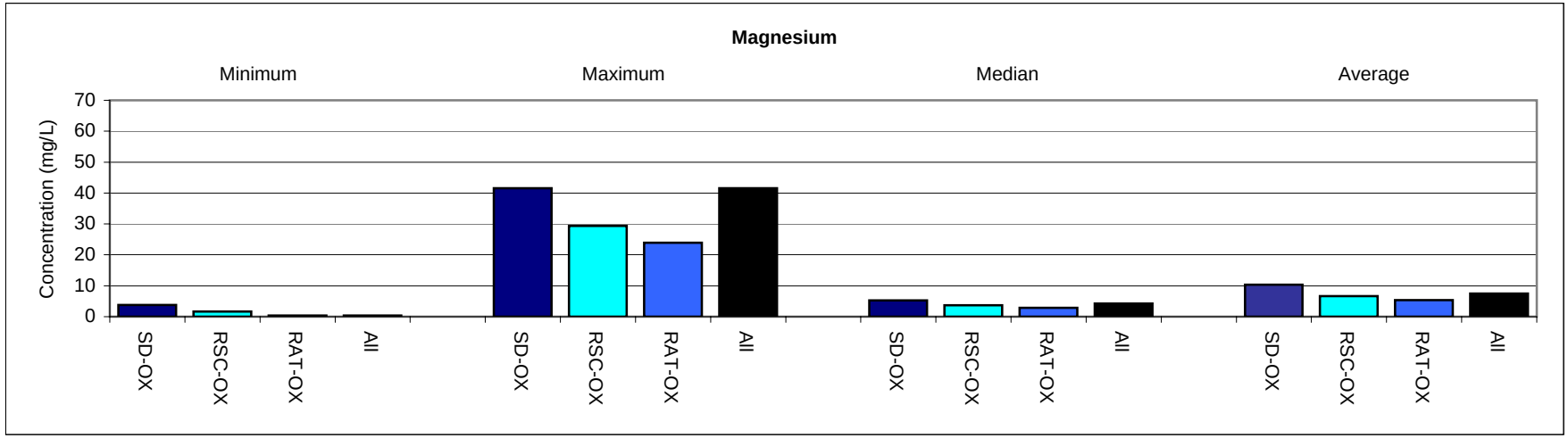
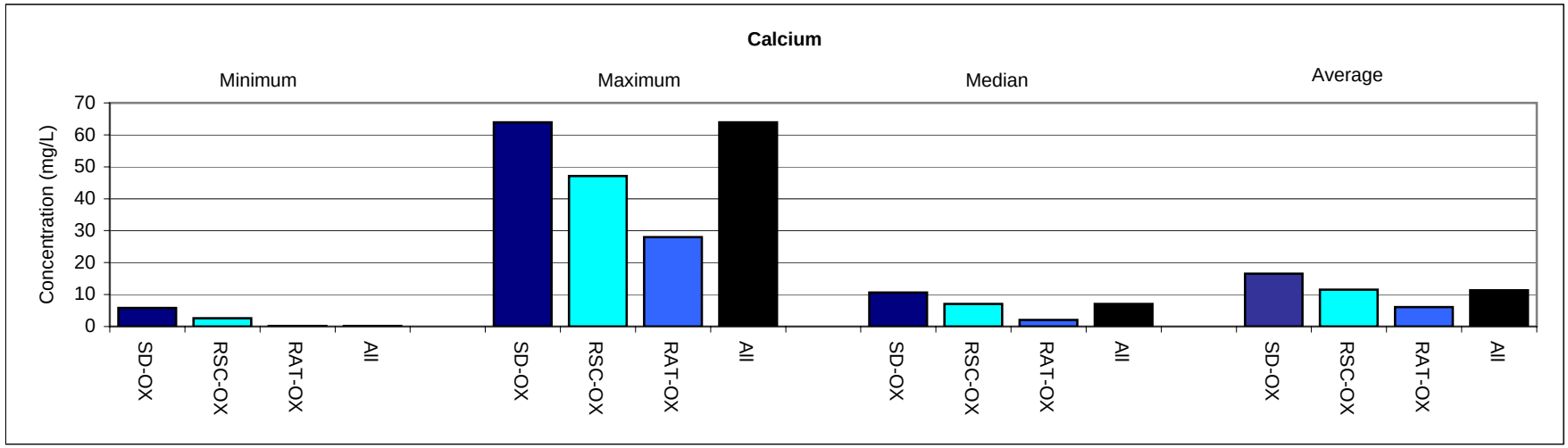
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Oxide SPLP Leachate Concentration Comparison - Alkalinity and pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Oxide Waste (Mar 07).xls	FIGURE NO.	**5.4-16**





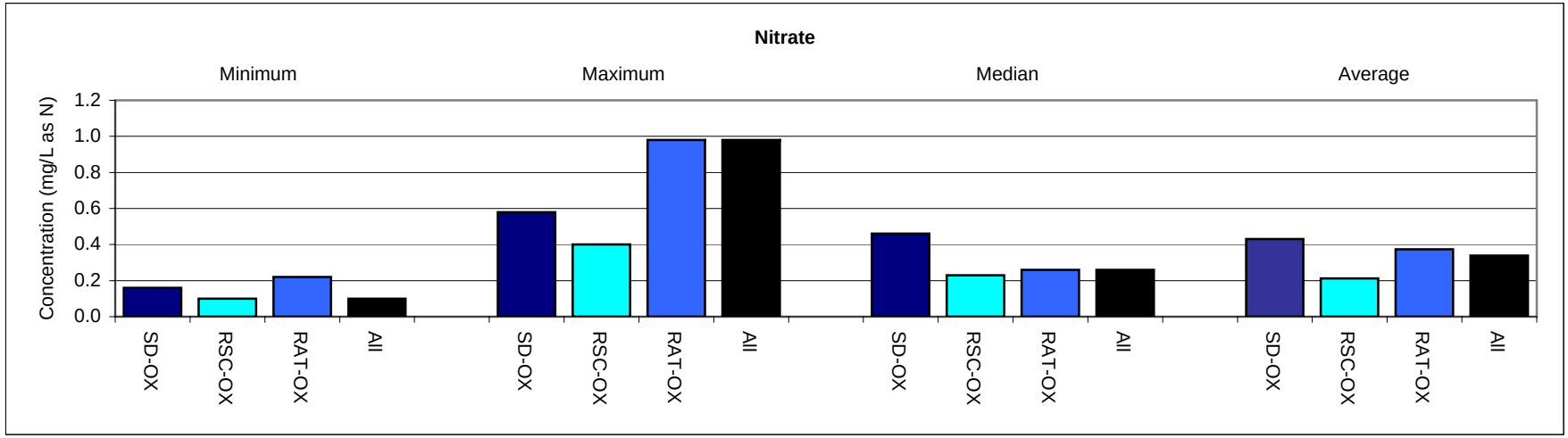
Golder Associates

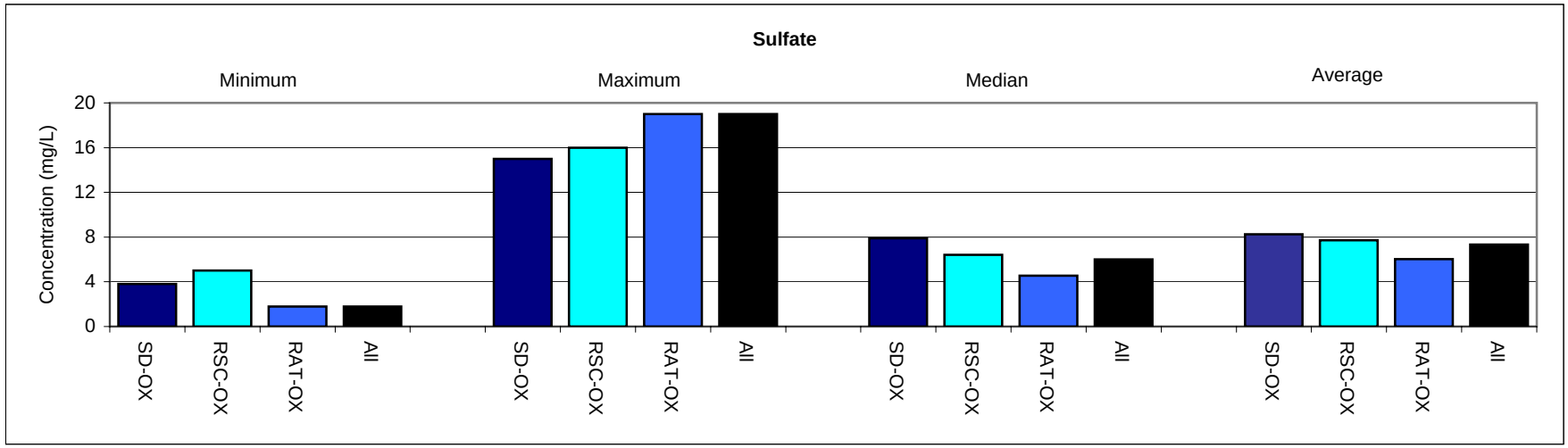
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Oxide SPLP Leachate Concentration Comparison - Magnesium and Calcium

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Oxide Waste (Mar 07).xls	FIGURE NO.	**5.4-17**





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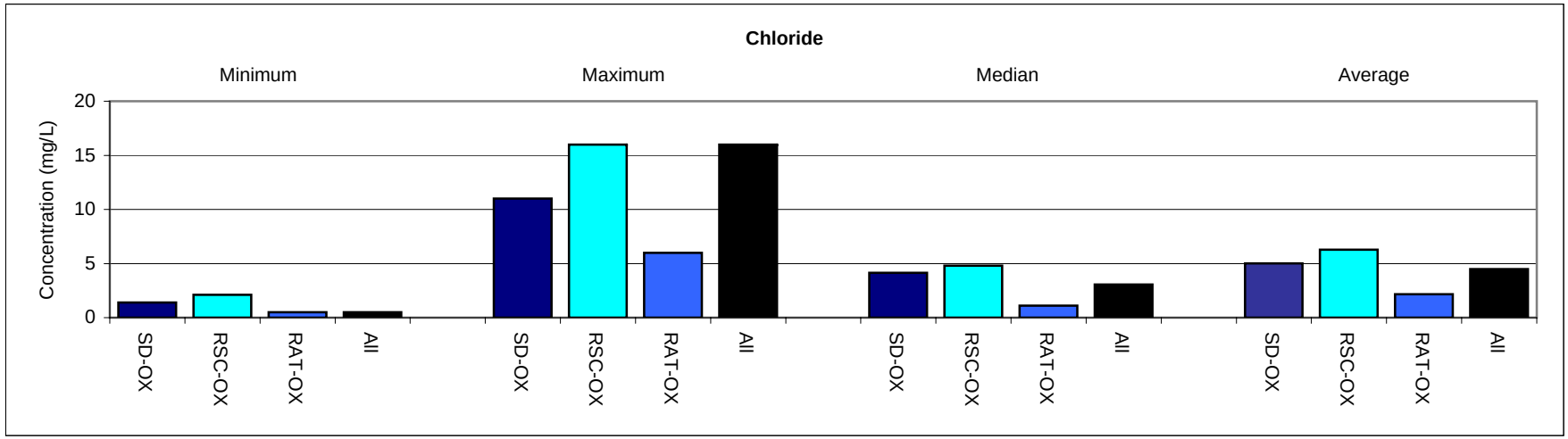
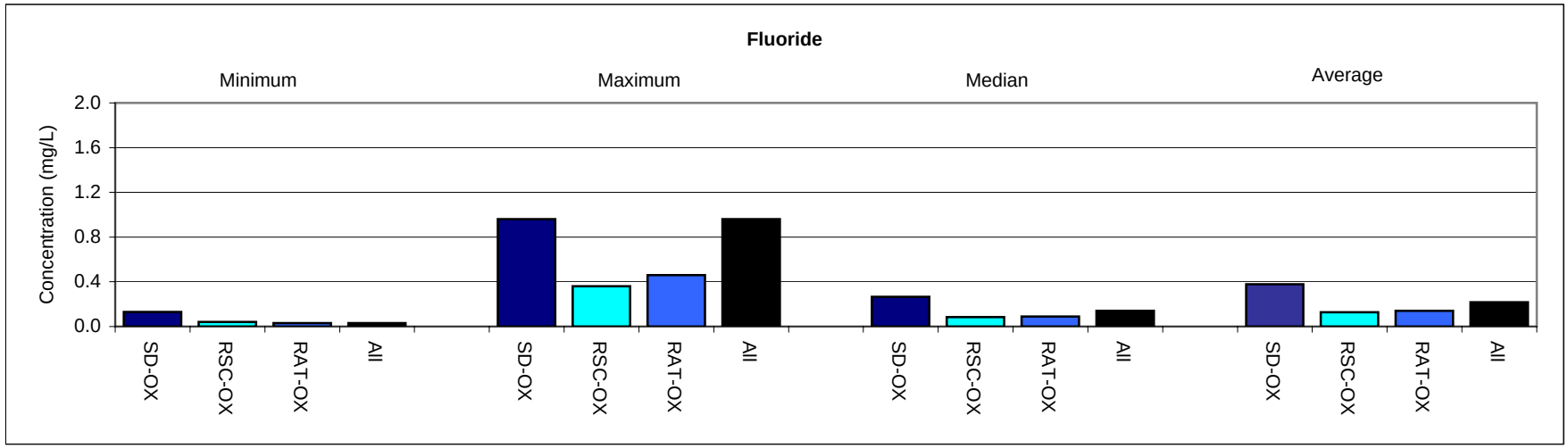
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Oxide SPLP Leachate Concentration Comparison - Nitrate and Sulfate

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Oxide Waste (Mar 07).xls	FIGURE NO.	**5.4-18**





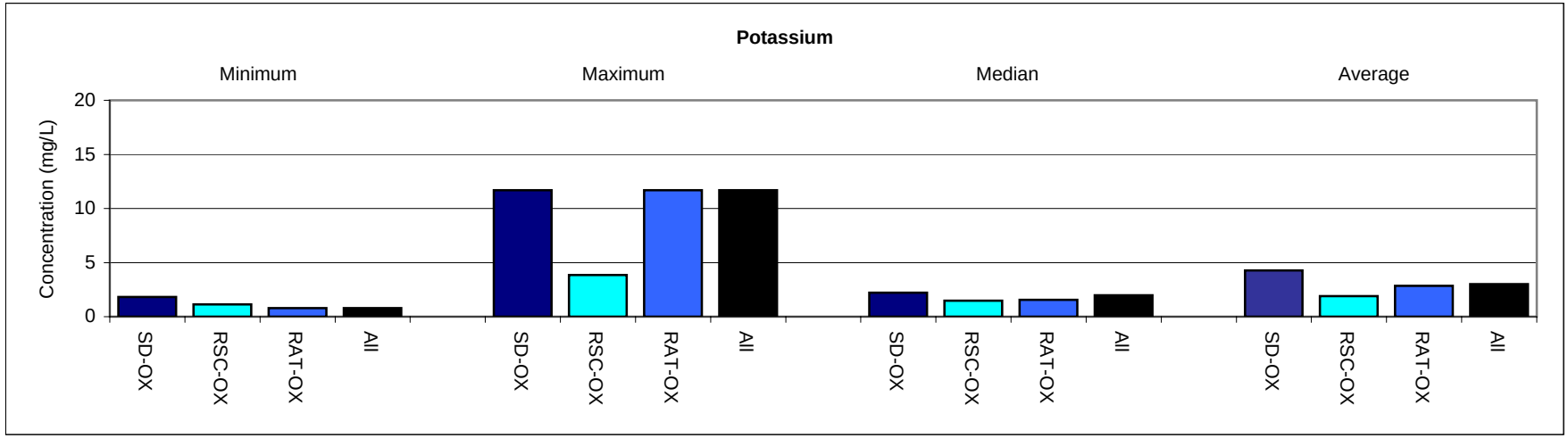
Golder Associates

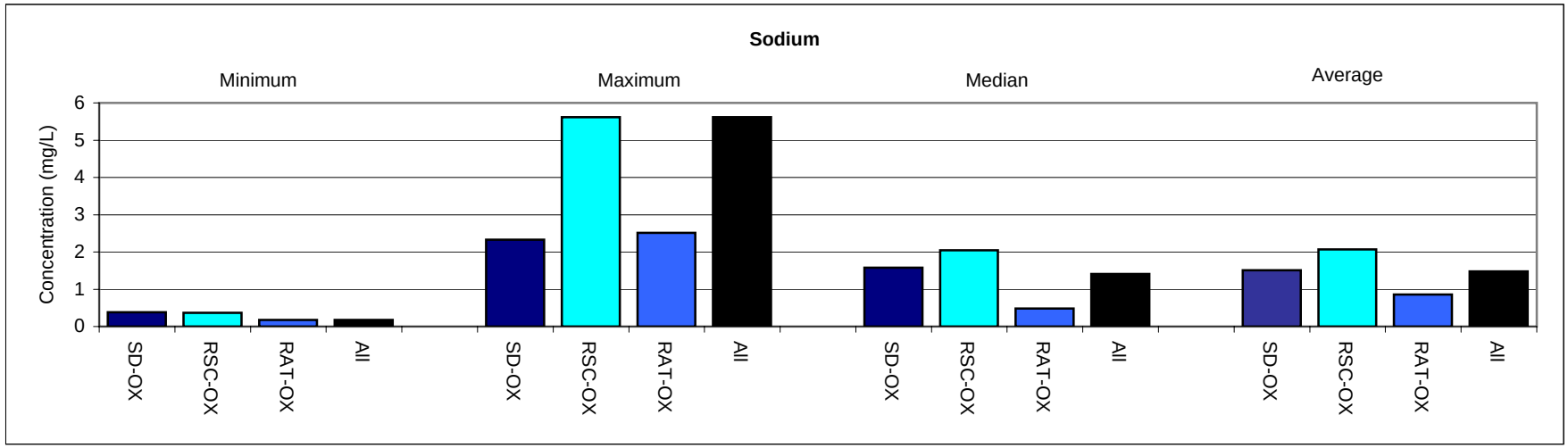
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Oxide SPLP Leachate Concentration Comparison - Chloride and Fluoride

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Oxide Waste (Mar 07).xls	FIGURE NO.	**5.4-19**





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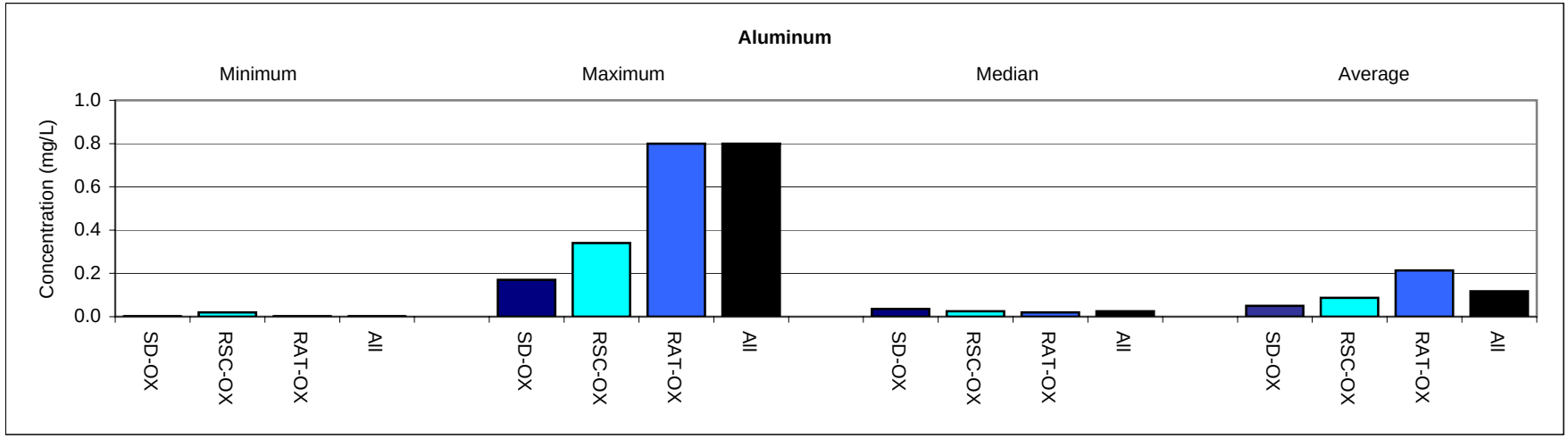
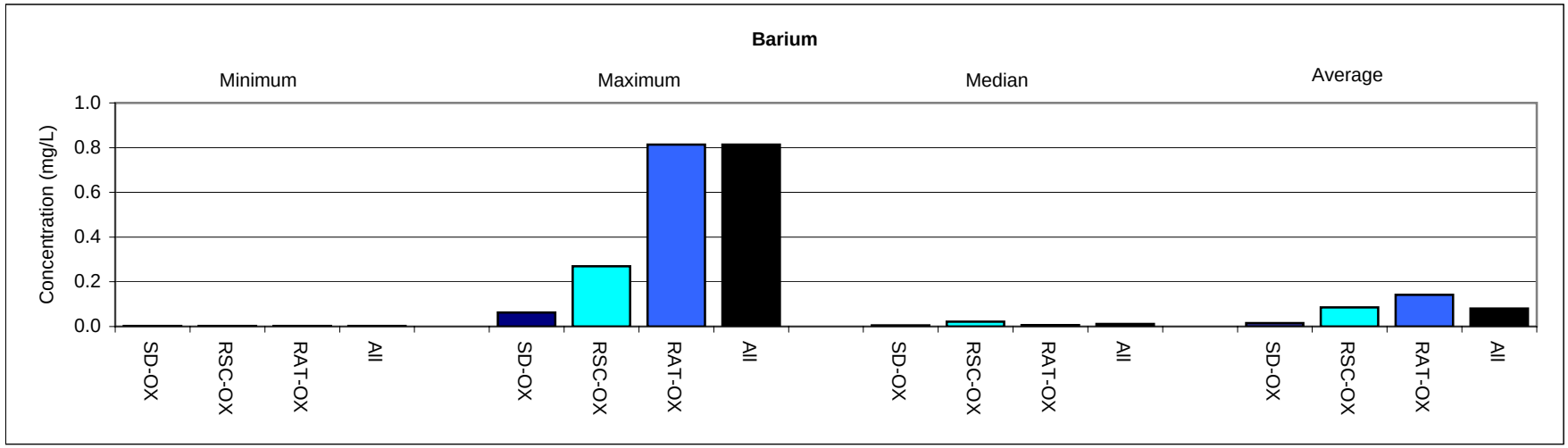
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Oxide SPLP Leachate Concentration Comparison - Potassium and Sodium

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Oxide Waste (Mar 07).xls	FIGURE NO.	**5.4-20**





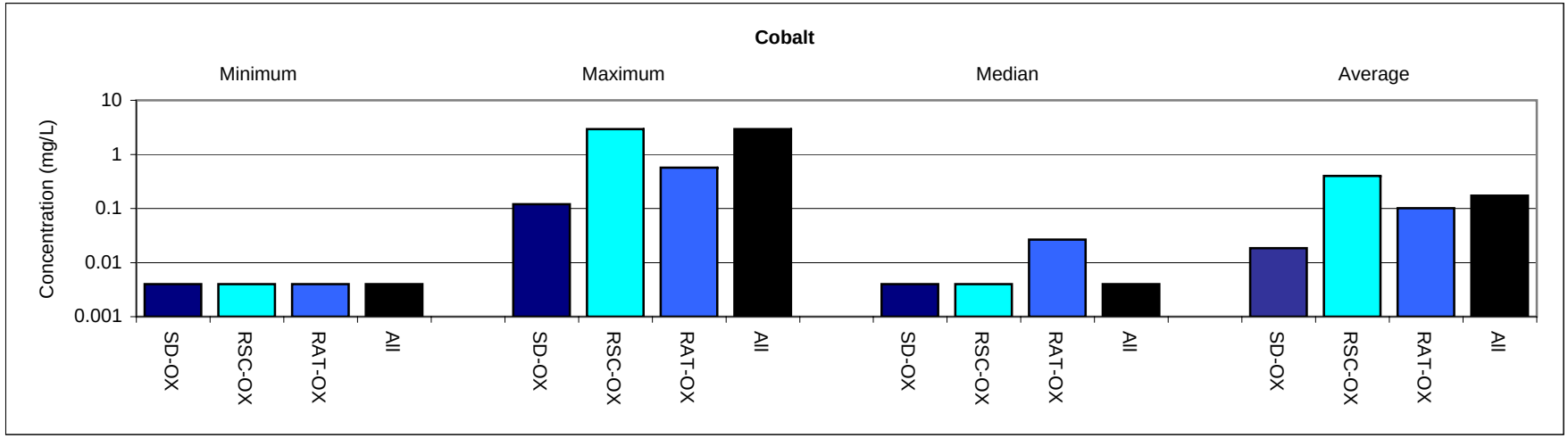
Golder Associates

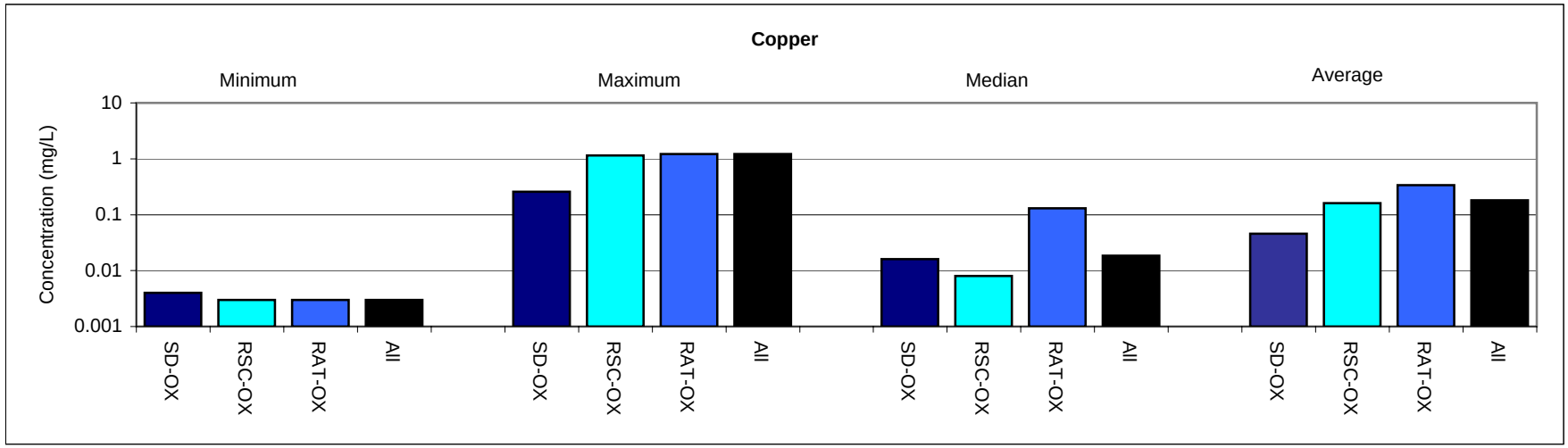
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Oxide SPLP Leachate Concentration Comparison - Aluminum and Barium

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Oxide Waste (Mar 07).xls	FIGURE NO.	**5.4-21**





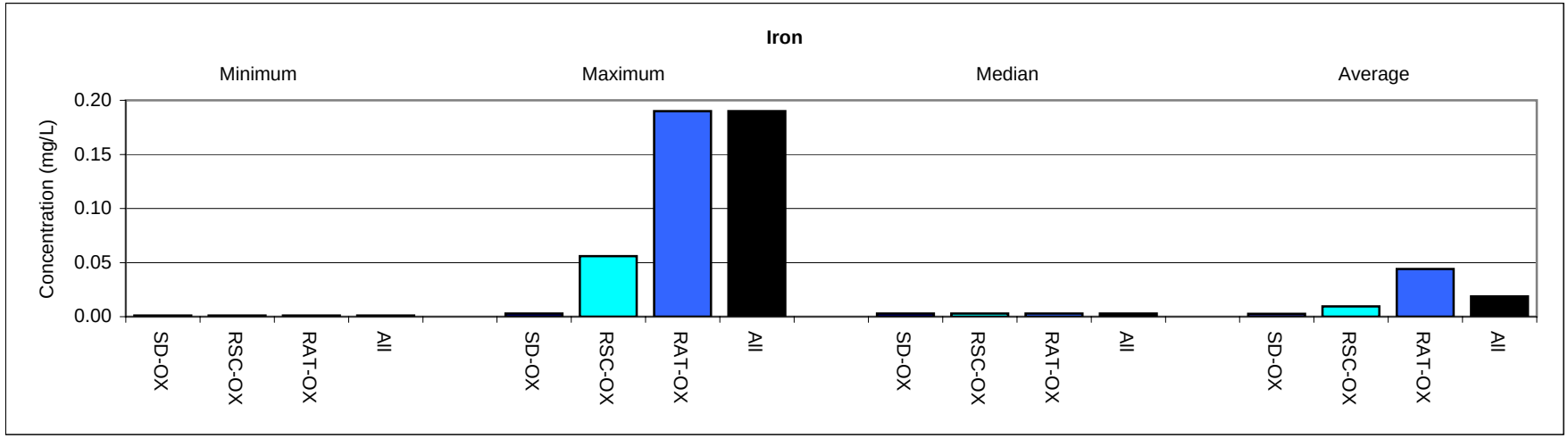
Golder Associates

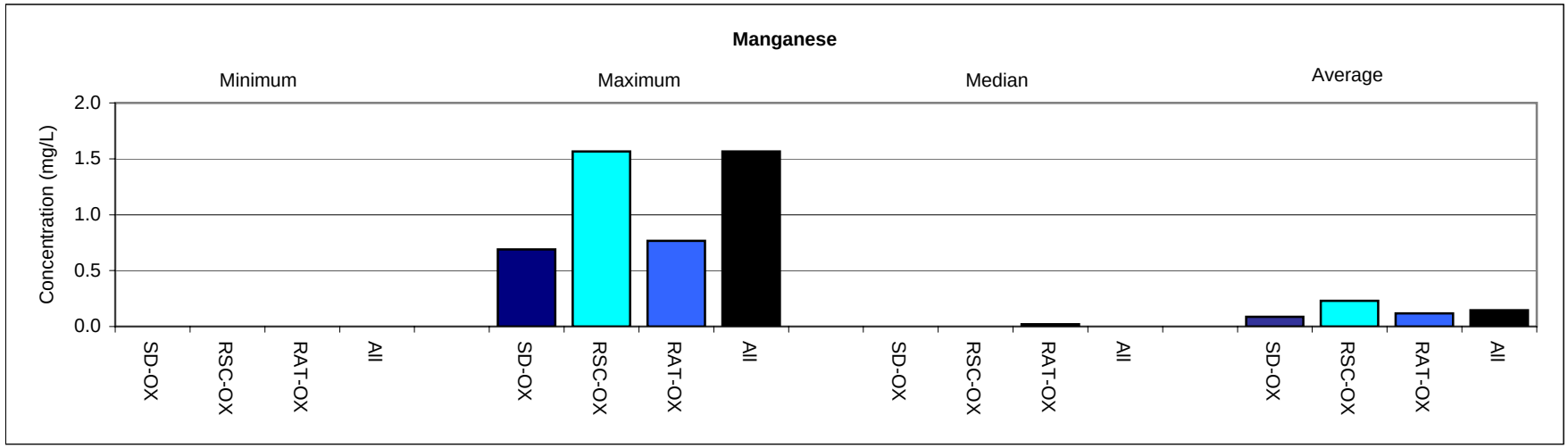
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Oxide SPLP Leachate Concentration Comparison - Cobalt and Copper

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Oxide Waste (Mar 07).xls	FIGURE NO.	**5.4-22**





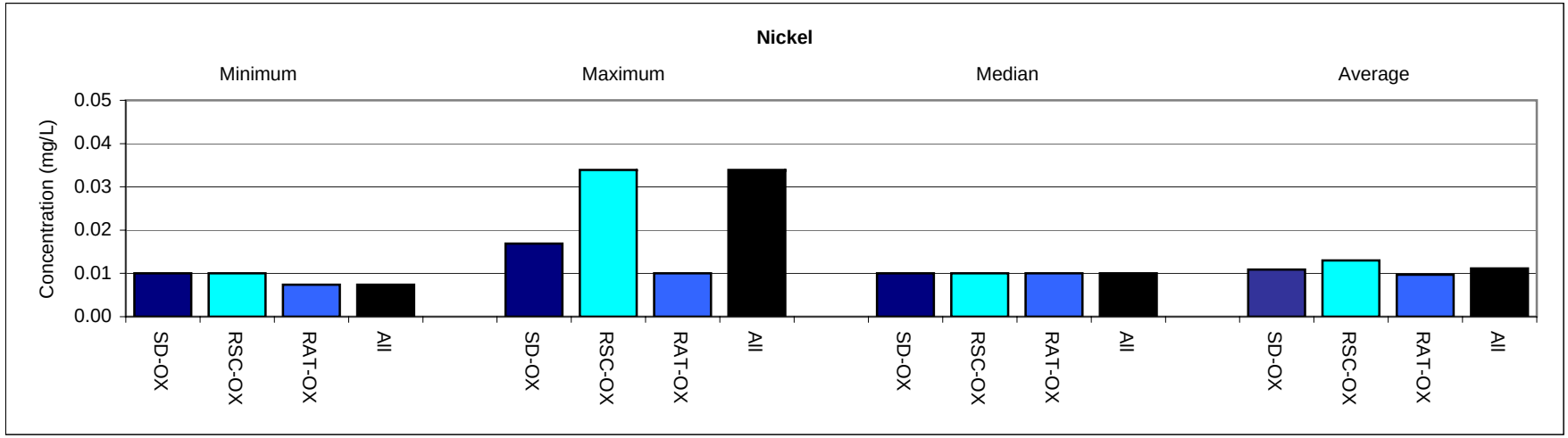
Golder Associates

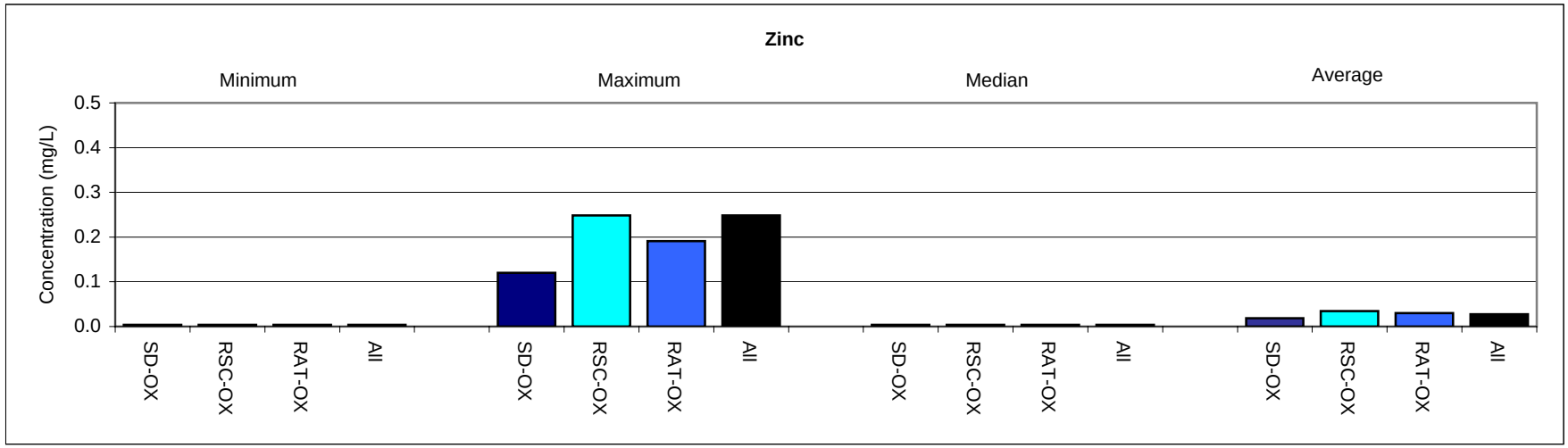
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Oxide SPLP Leachate Concentration Comparison - Iron and Manganese

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Oxide Waste (Mar 07).xls	FIGURE NO.	**5.4-23**





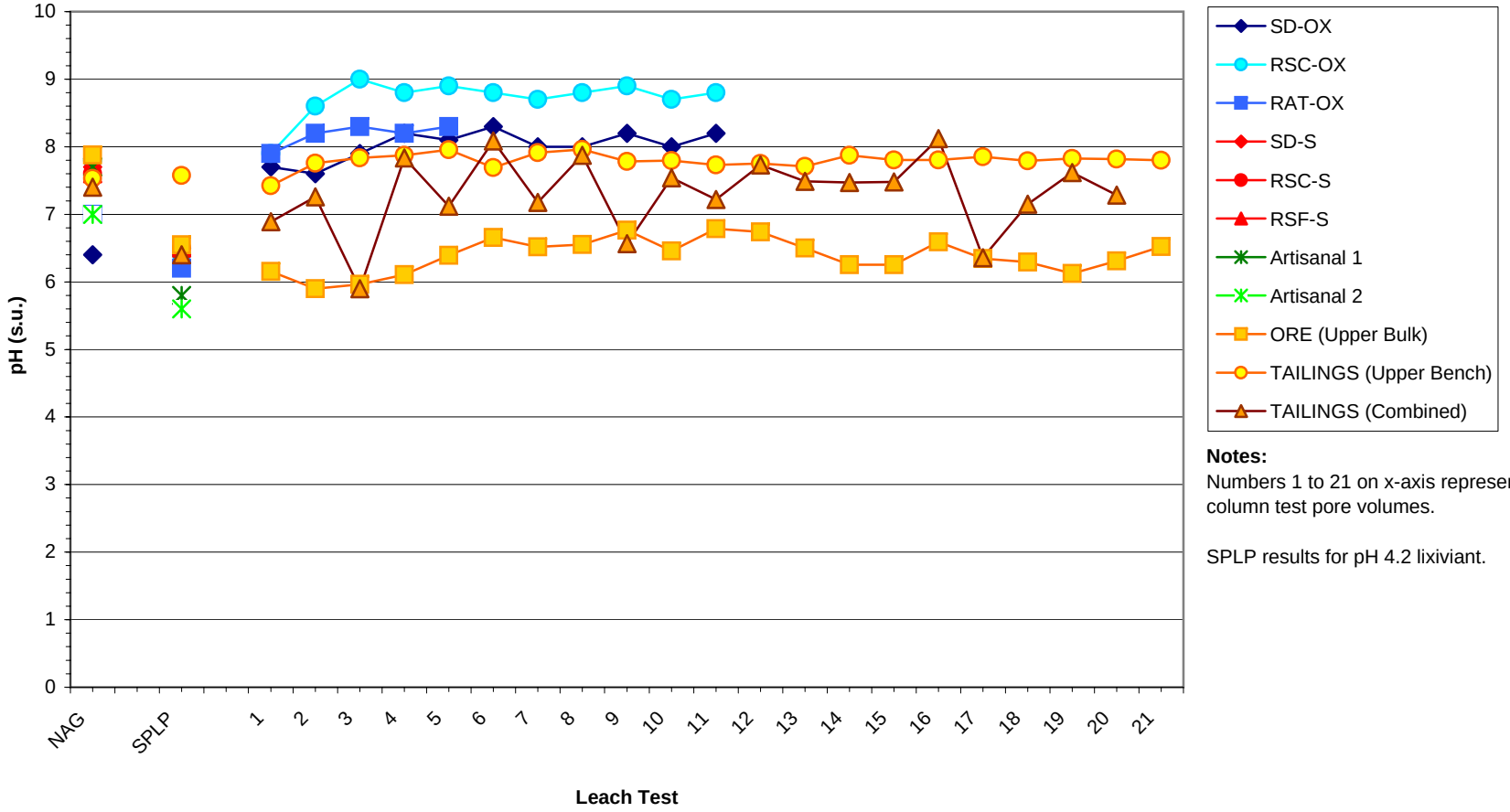
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Oxide SPLP Leachate Concentration Comparison - Nickel and Zinc

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - SPLP Oxide Waste (Mar 07).xls	FIGURE NO.	**5.4-24**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

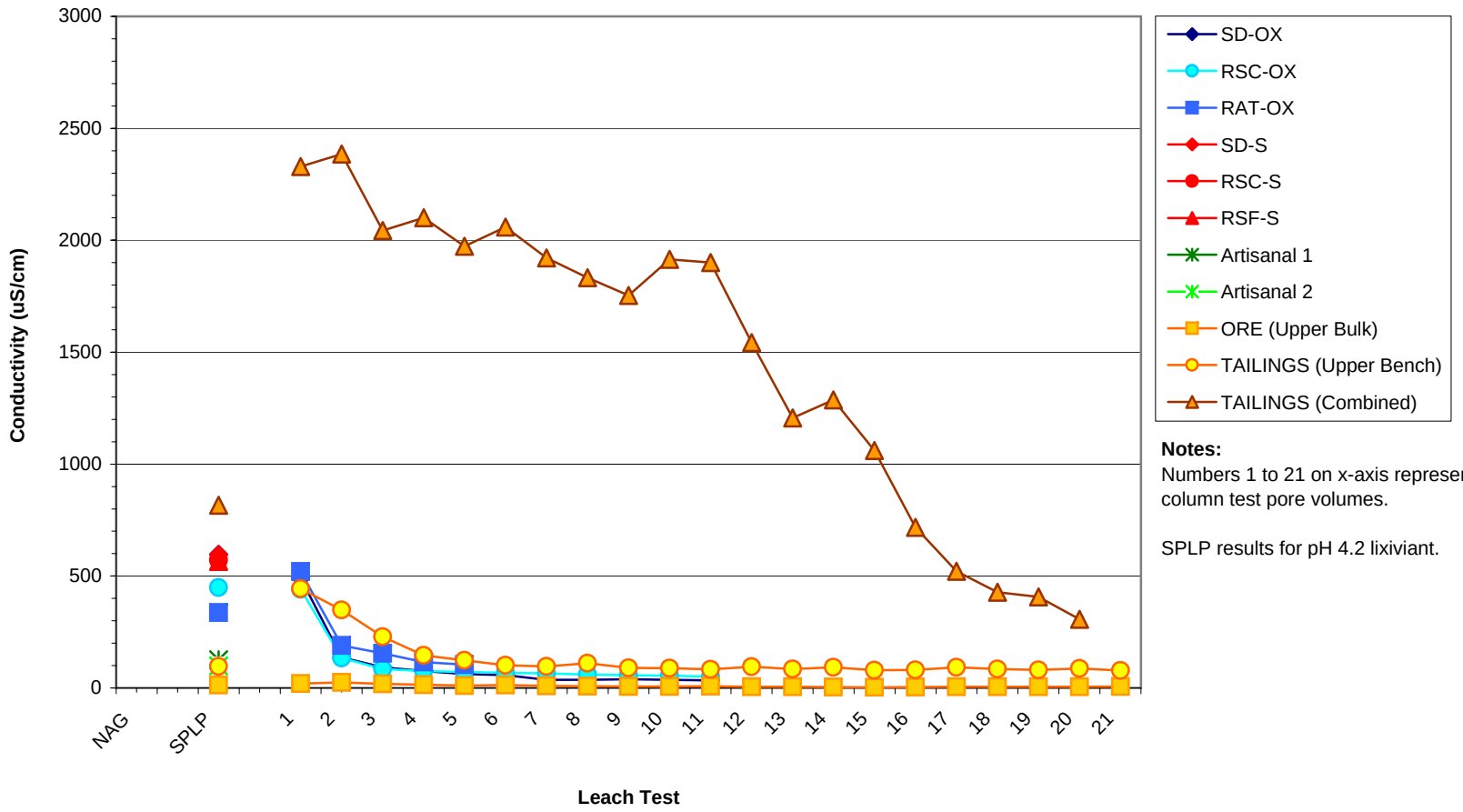
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-25**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

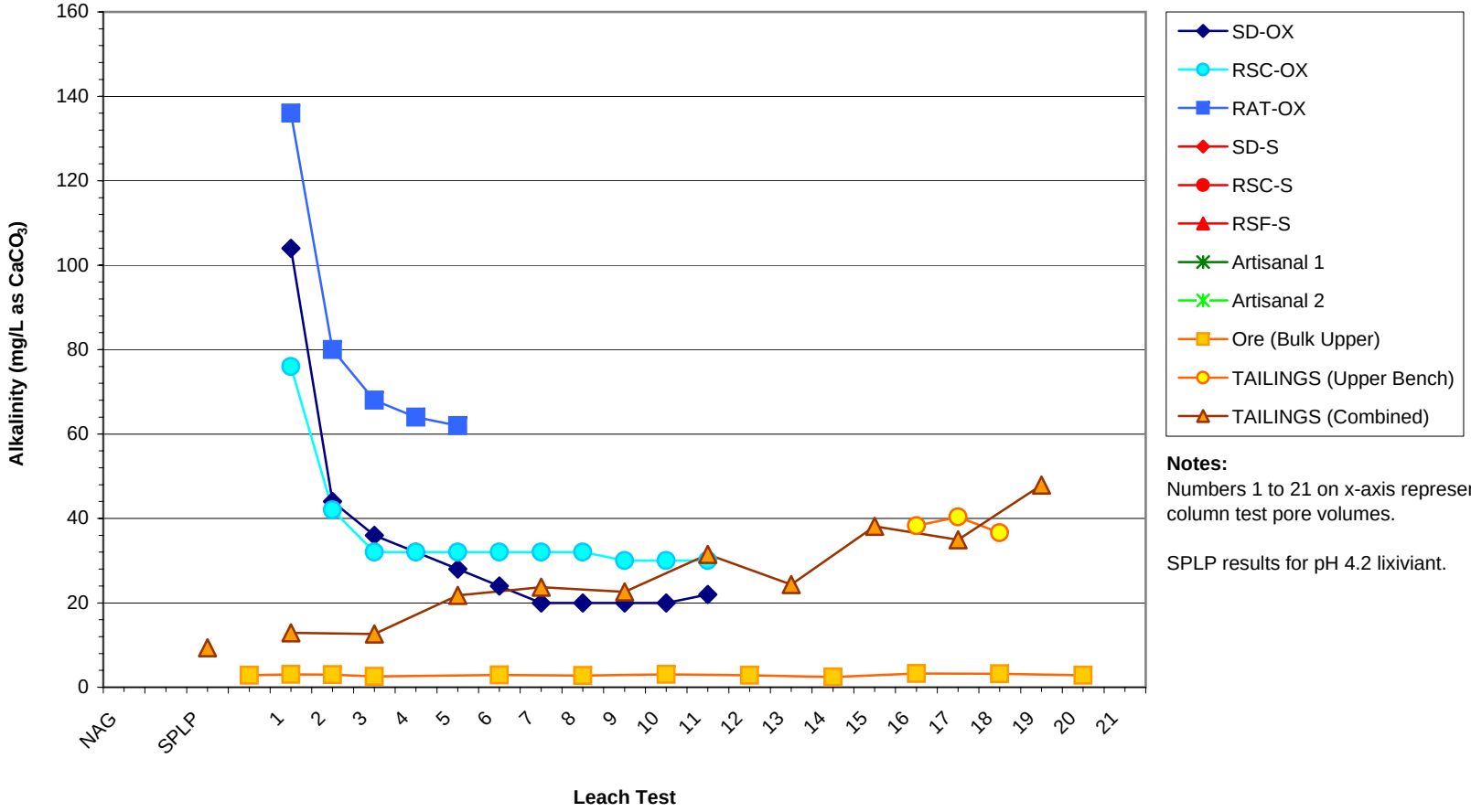
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Conductivity

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-26**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

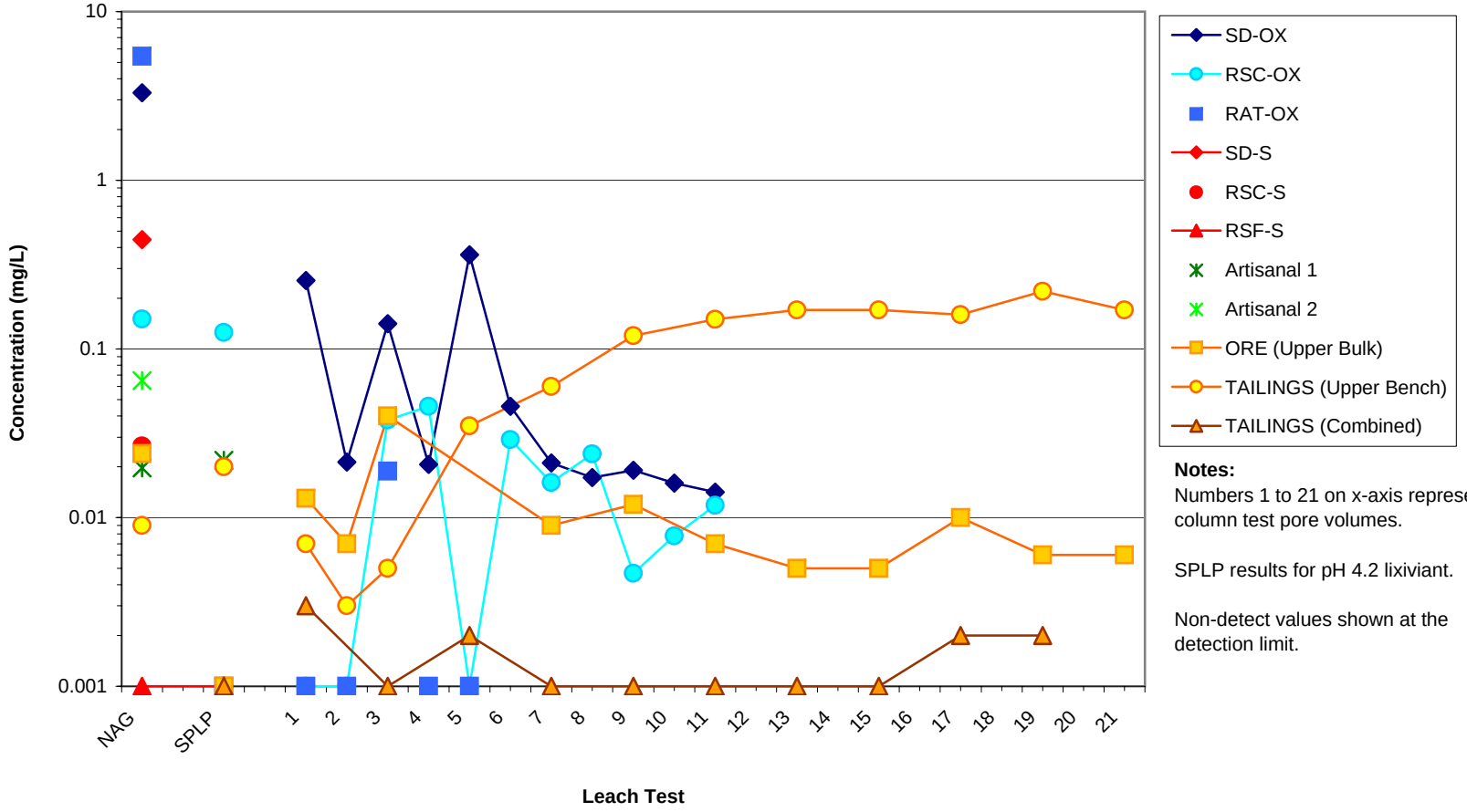
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Alkalinity

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-27**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

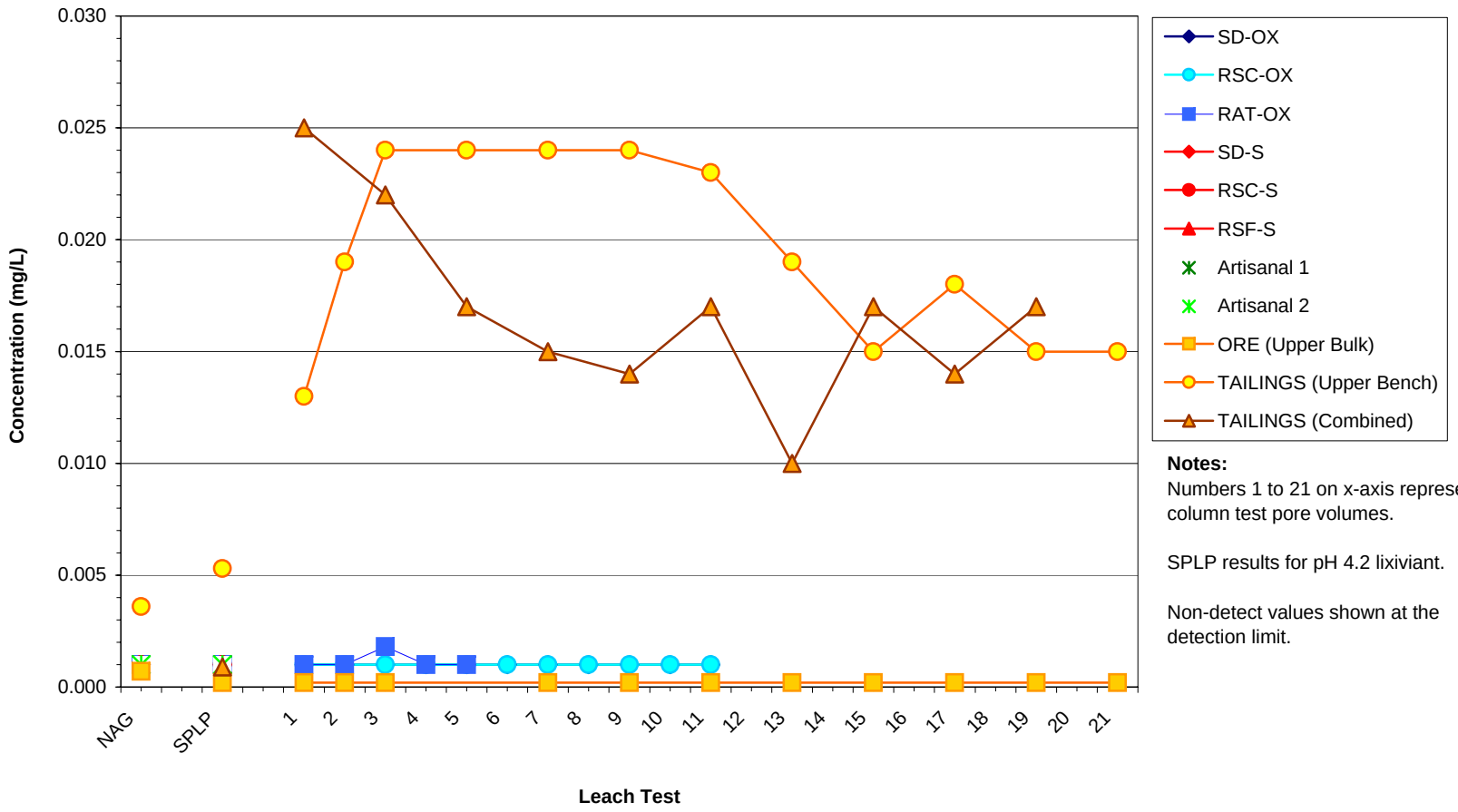
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Aluminum

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-28**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

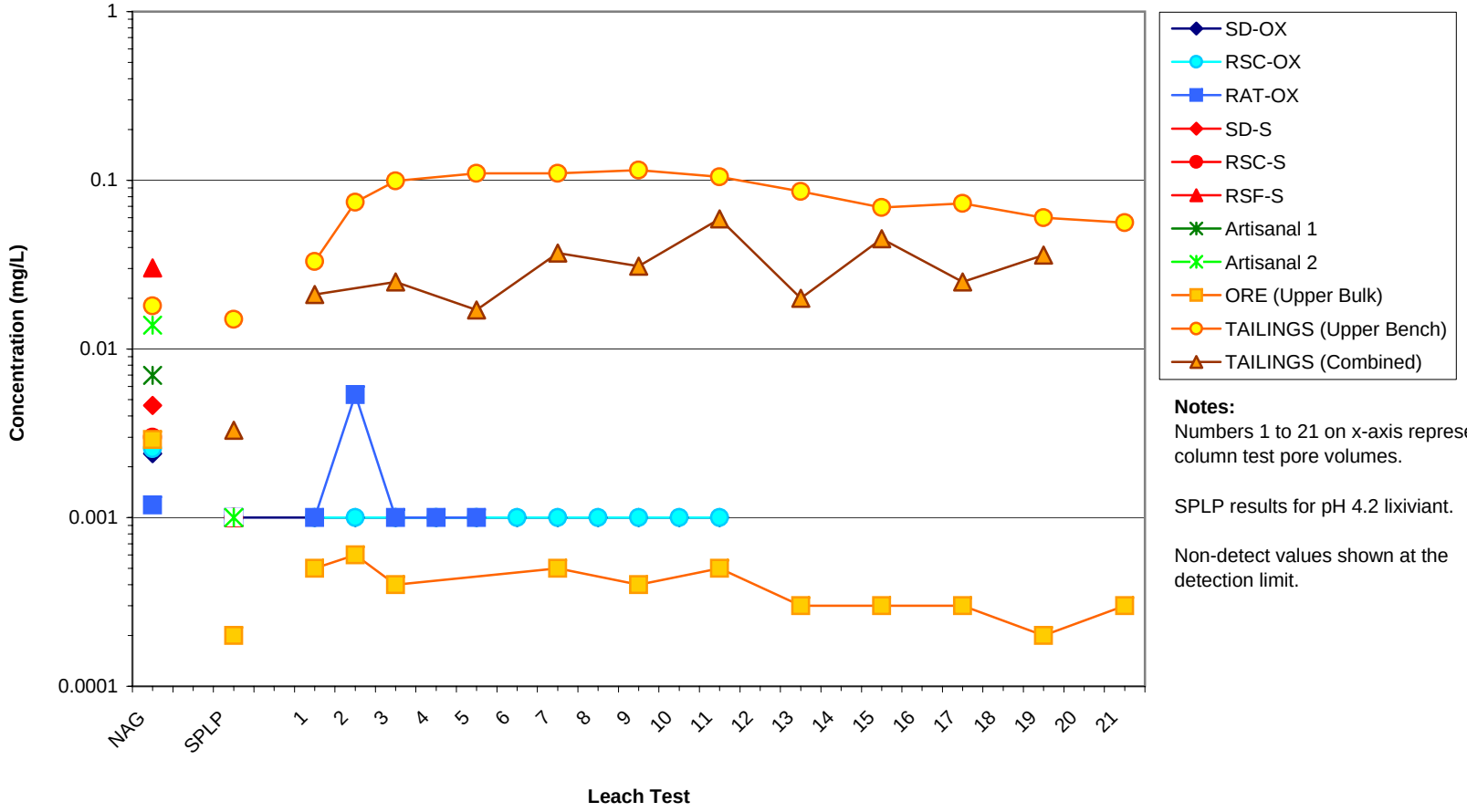
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Antimony

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-29**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

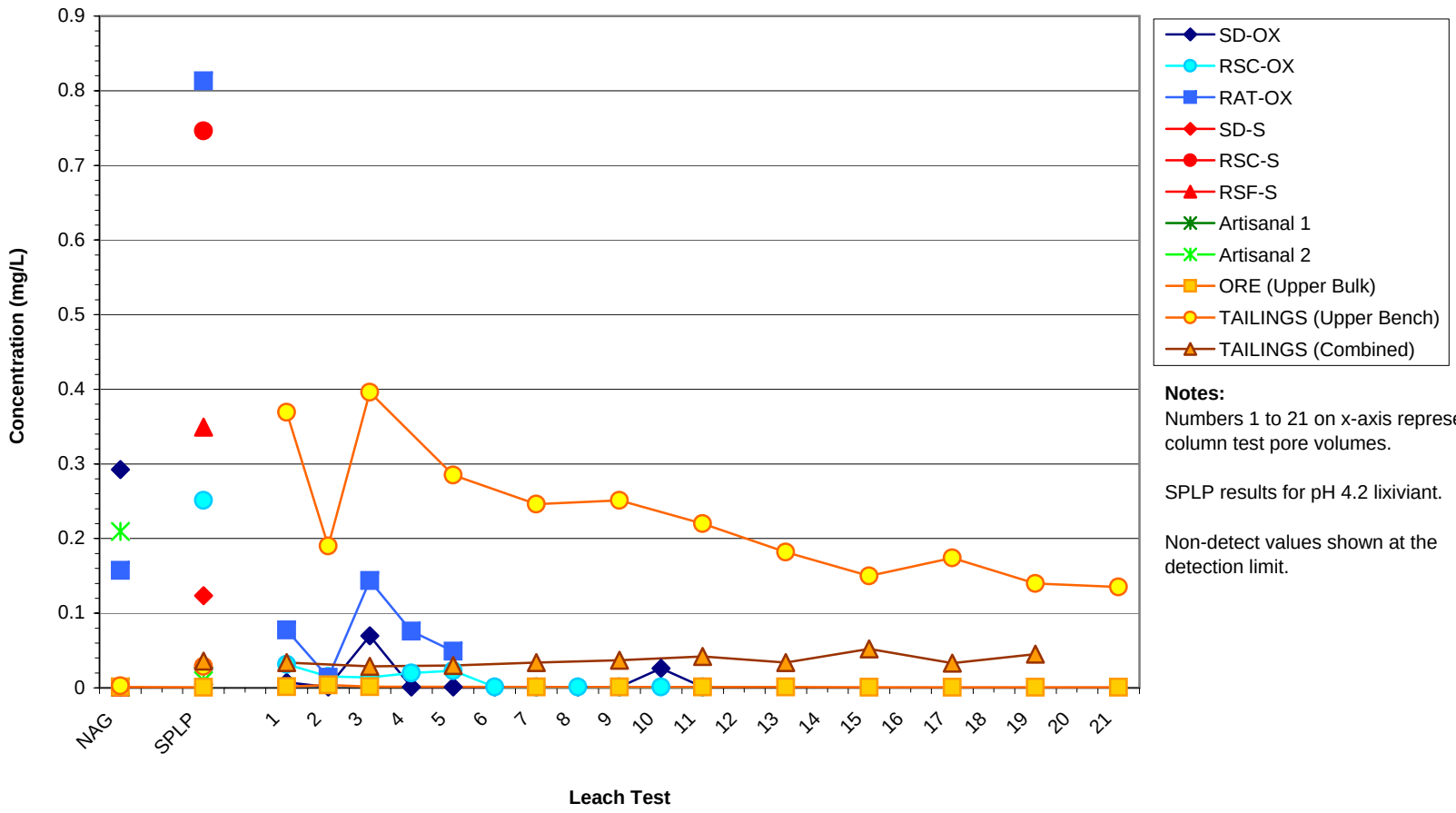
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Arsenic

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-30**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

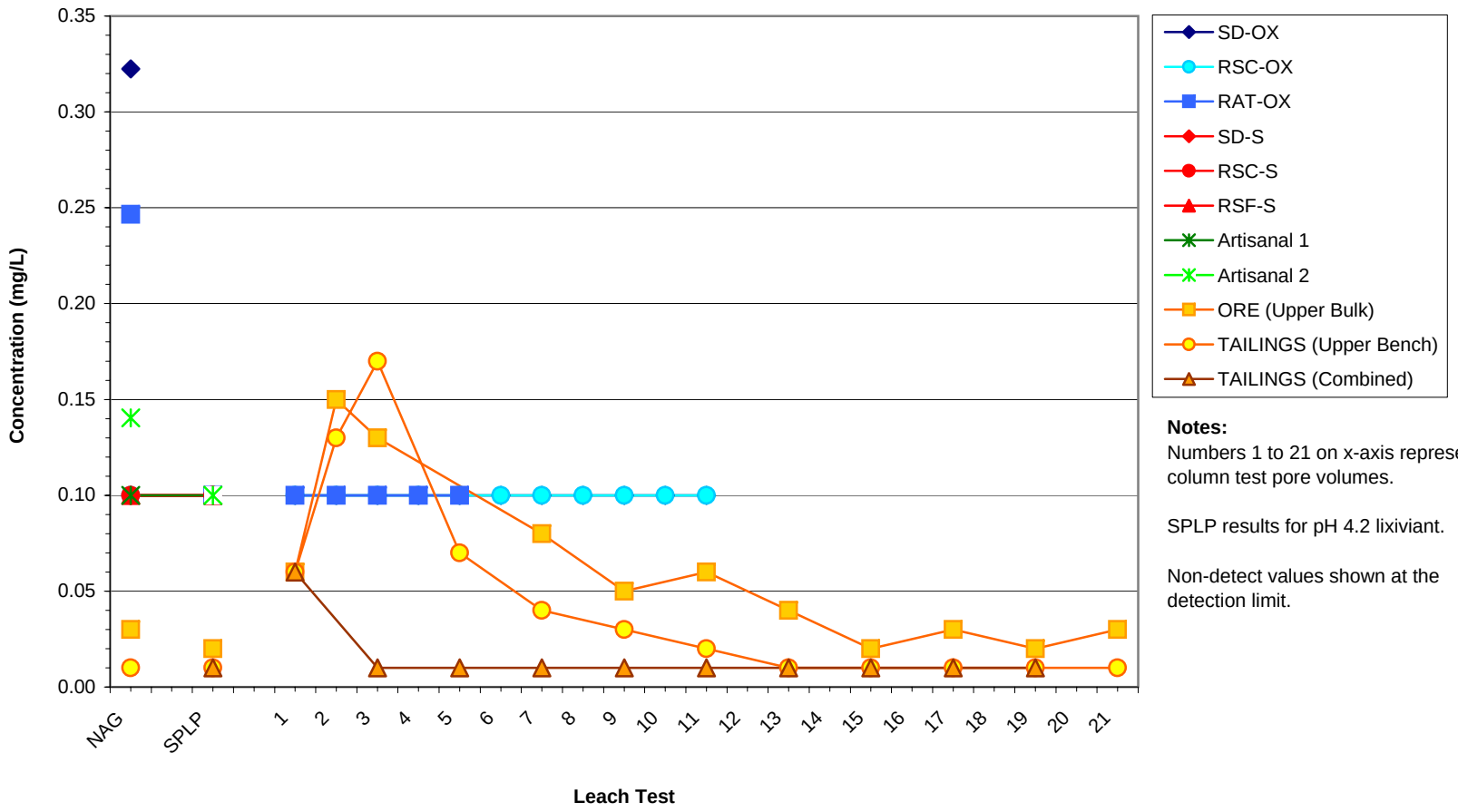
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Barium

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-31**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

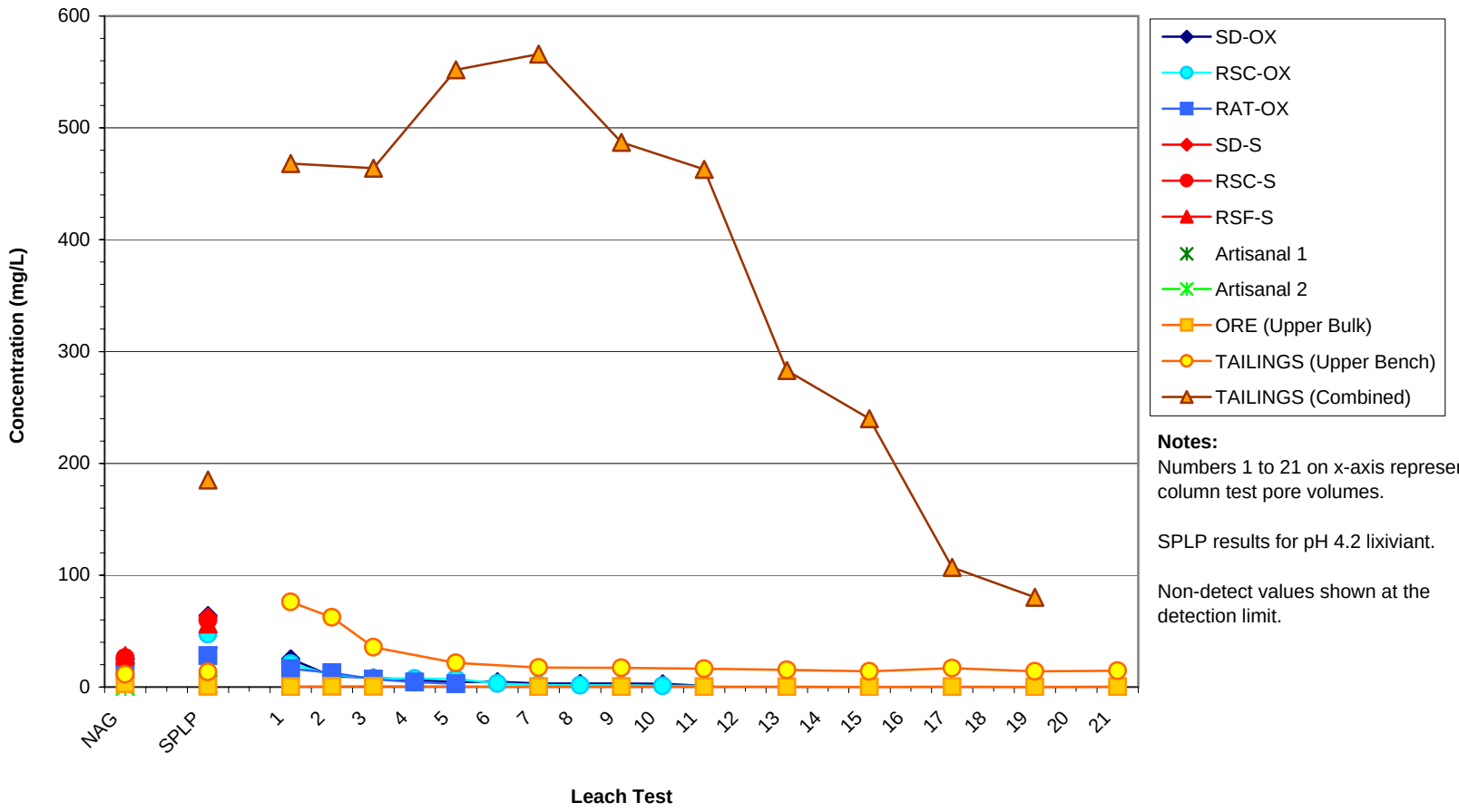
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Boron

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-32**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

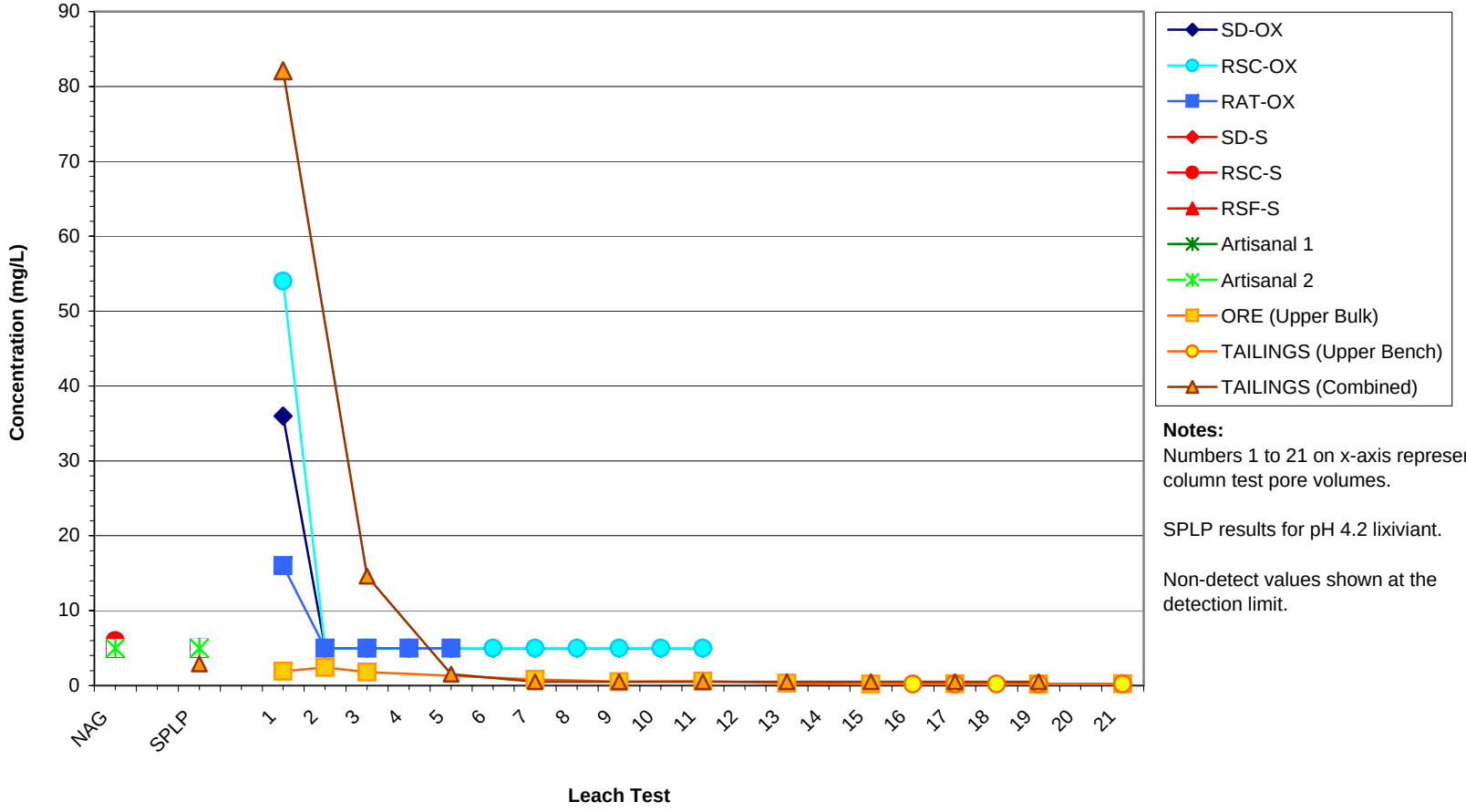
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Calcium

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-33**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

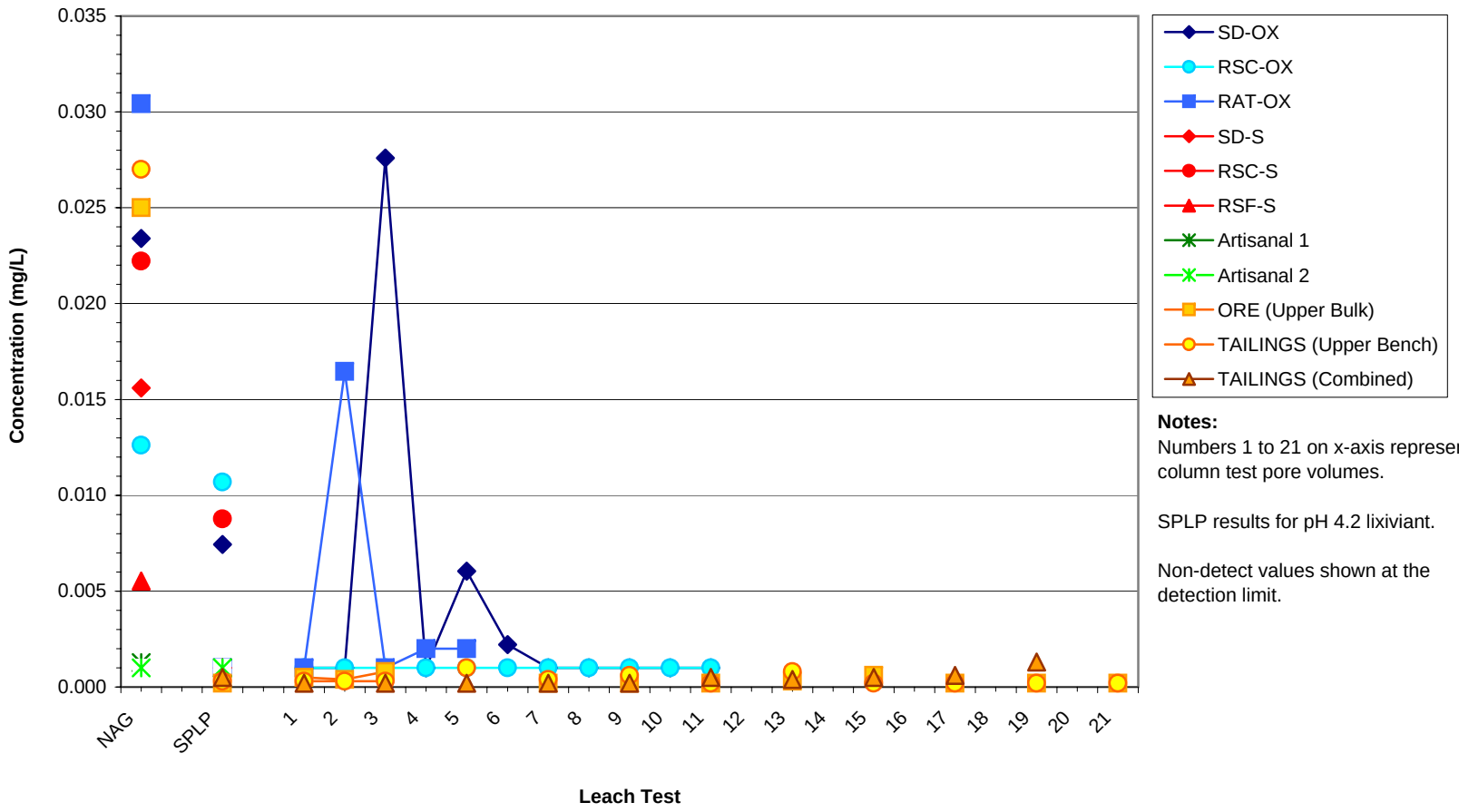
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Chloride

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-34**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

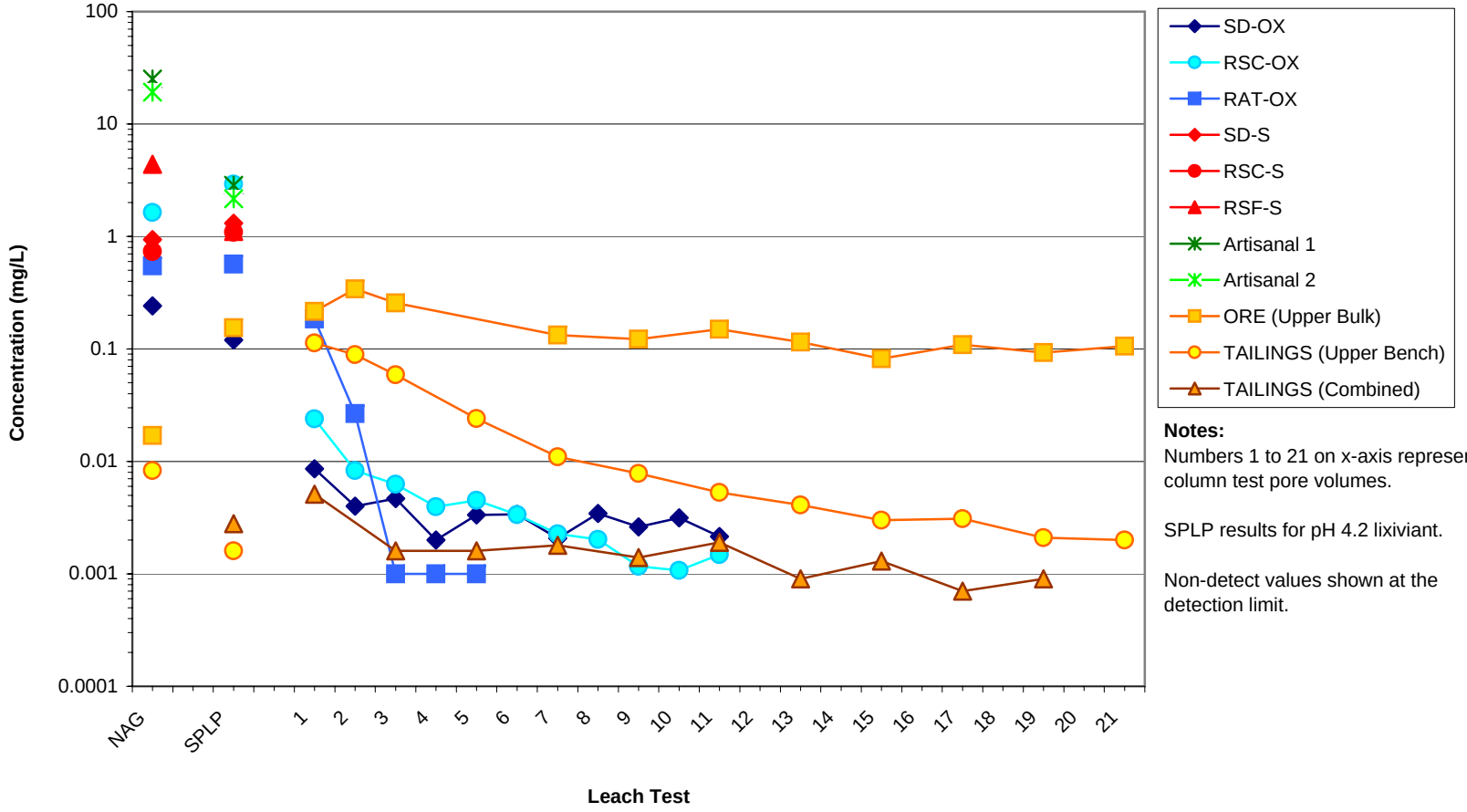
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Chromium

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-35**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

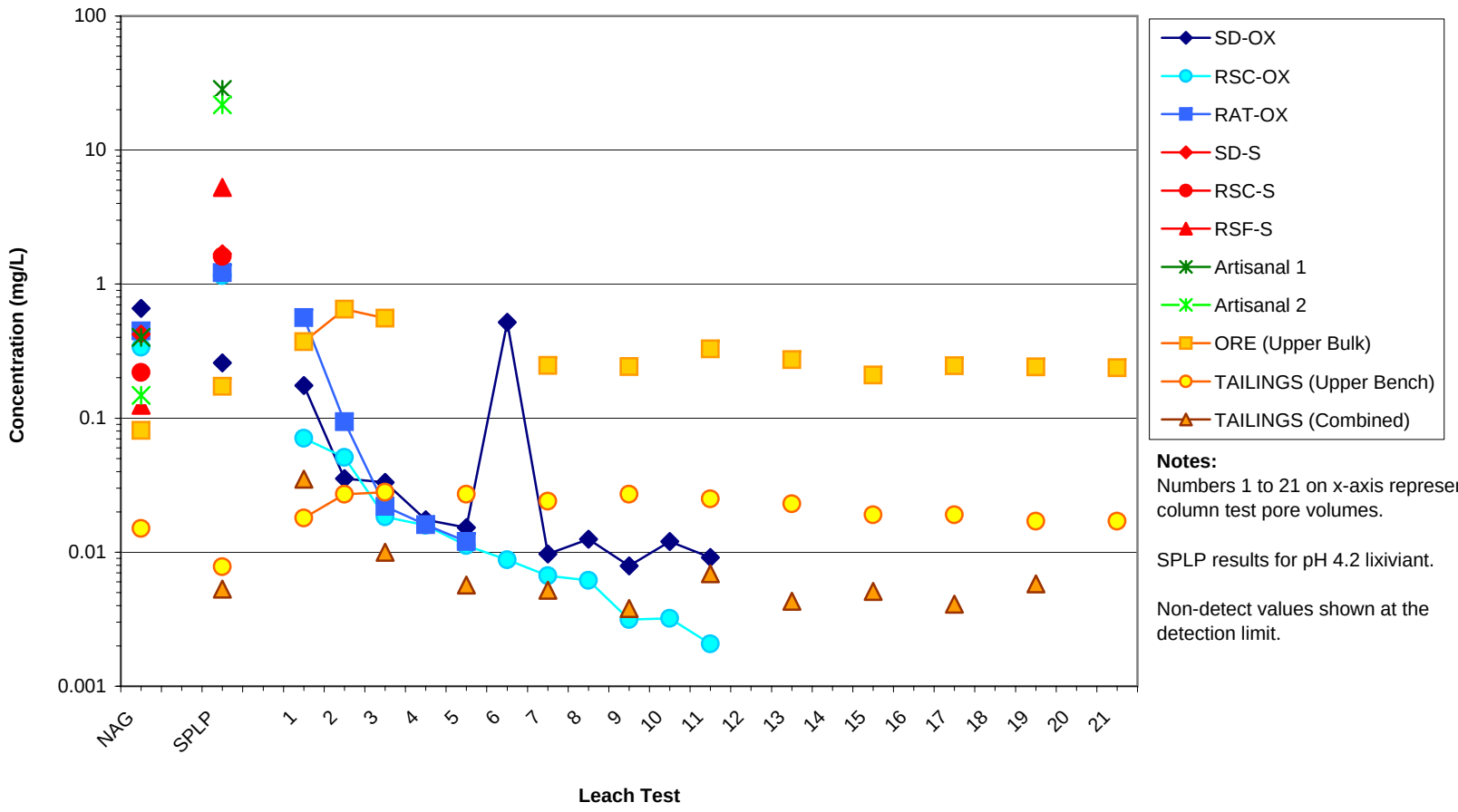
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Cobalt

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-36**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

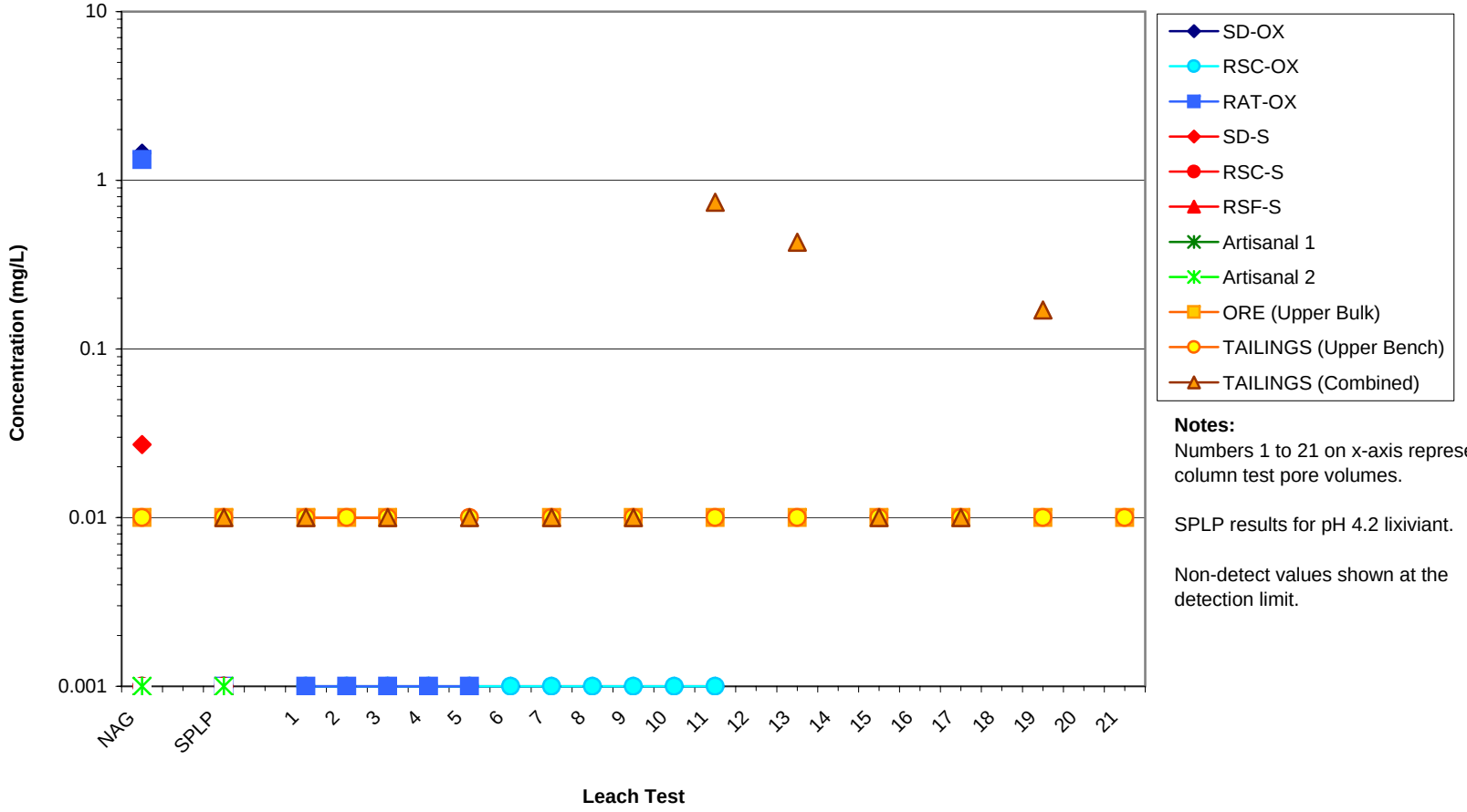
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Copper

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-37**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

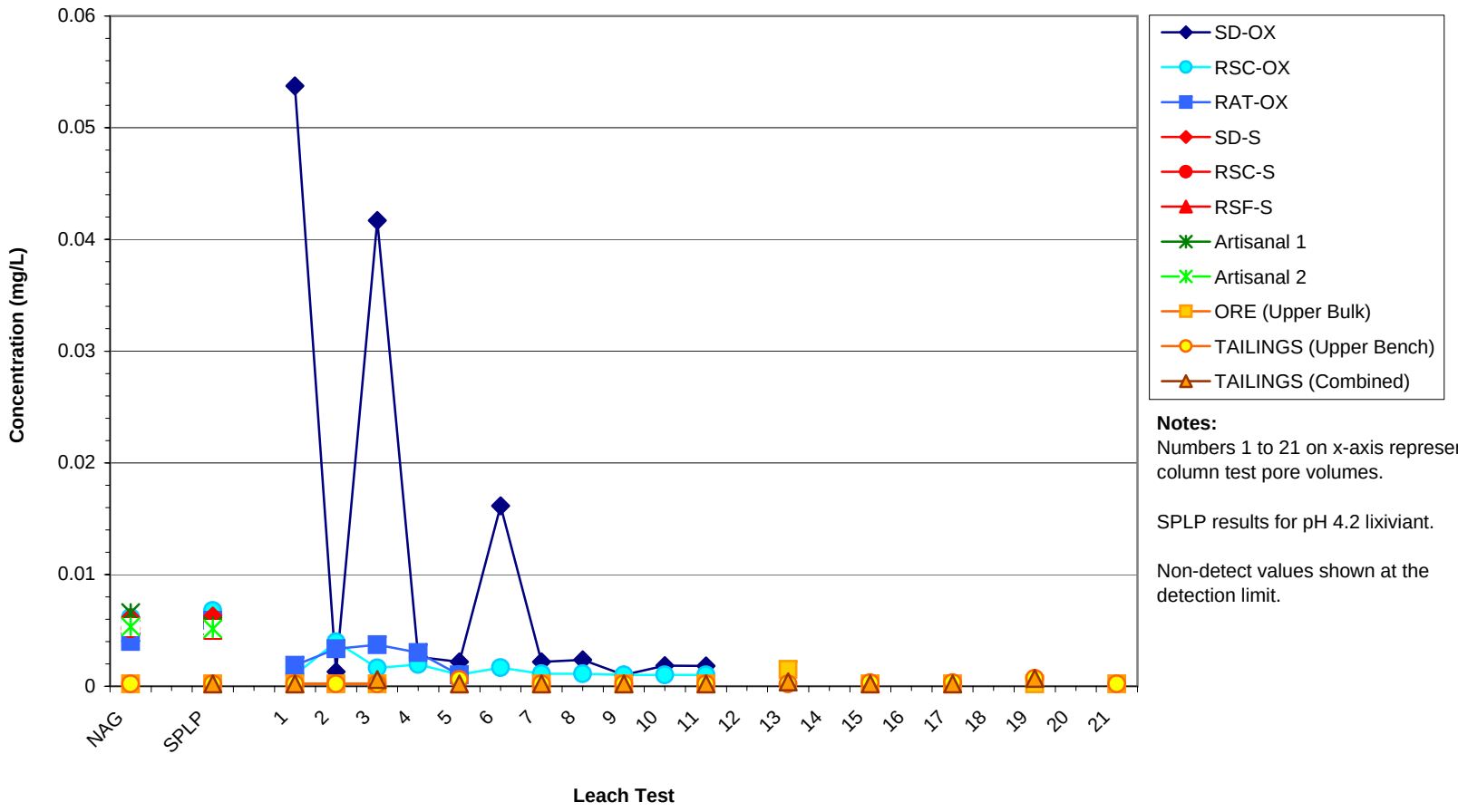
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Iron

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-38**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

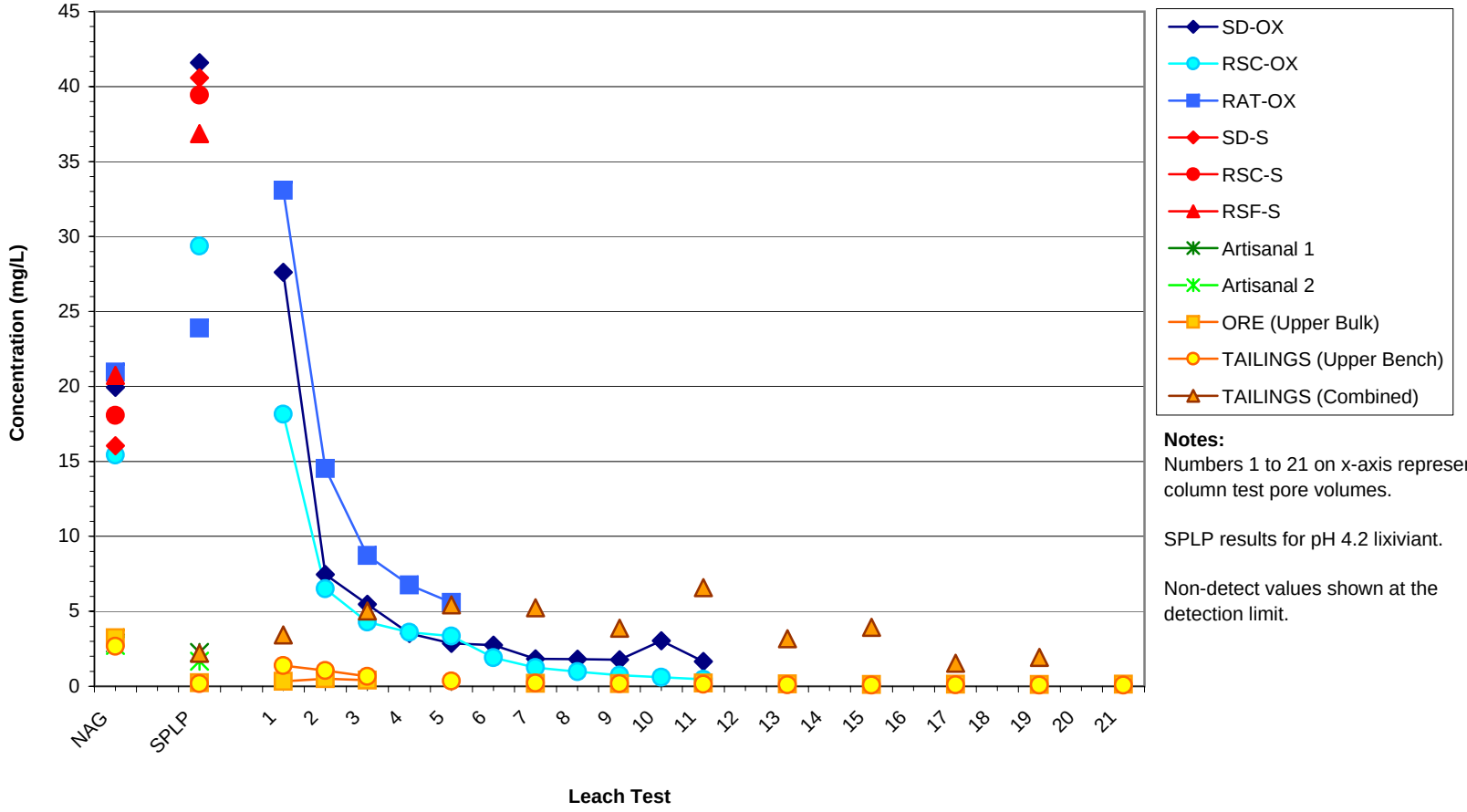
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Lead

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-39**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

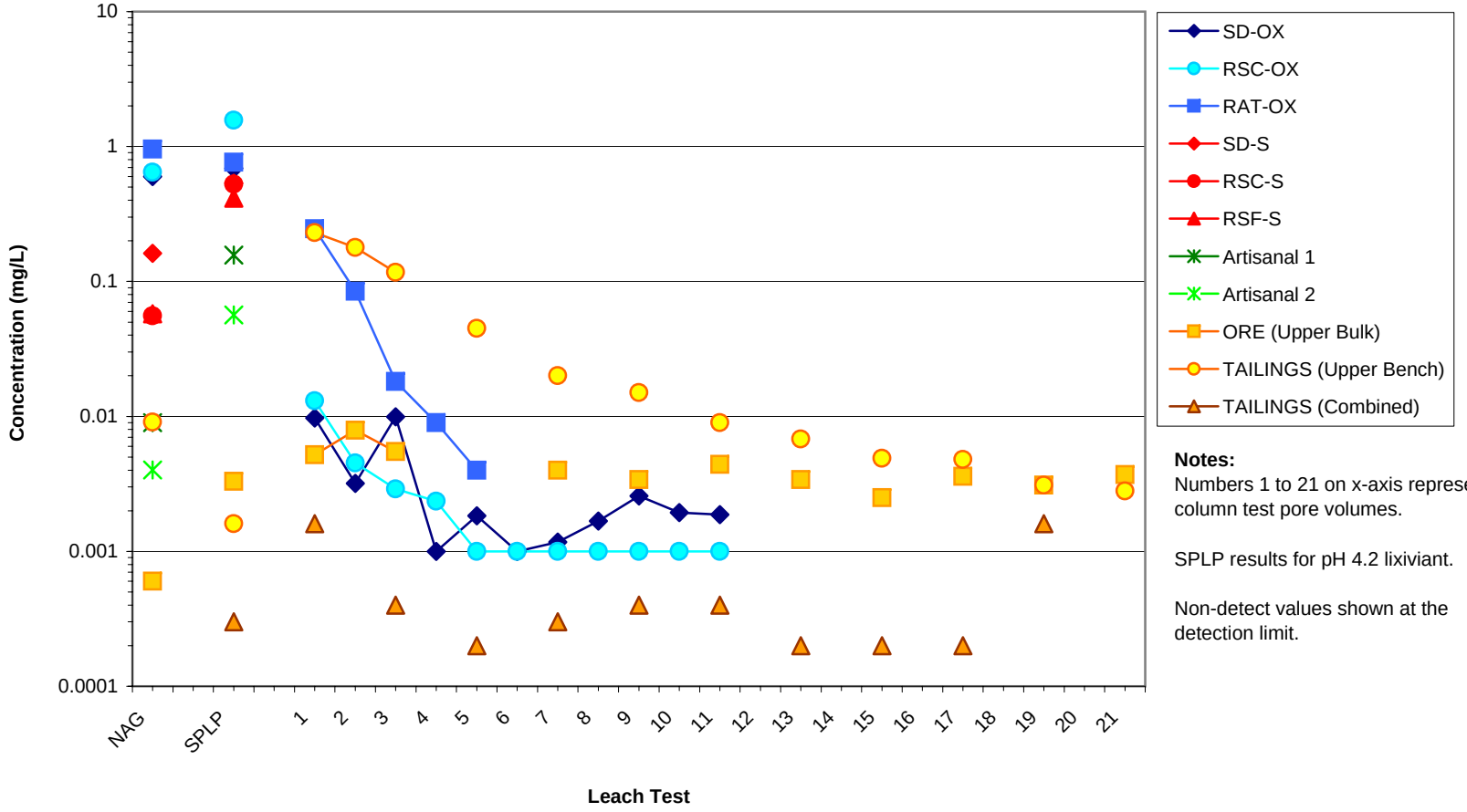
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Magnesium

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-40**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

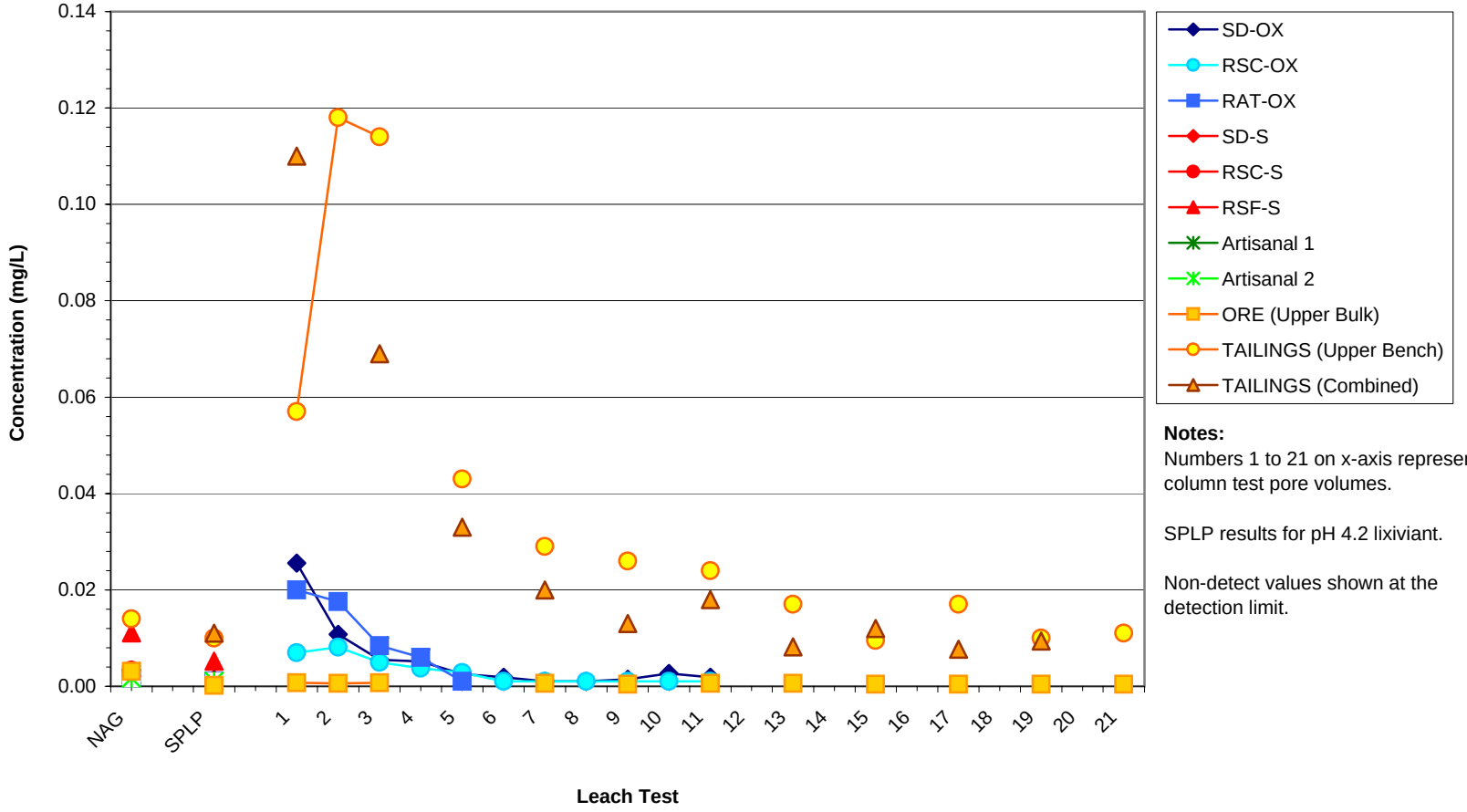
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Manganese

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-41**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

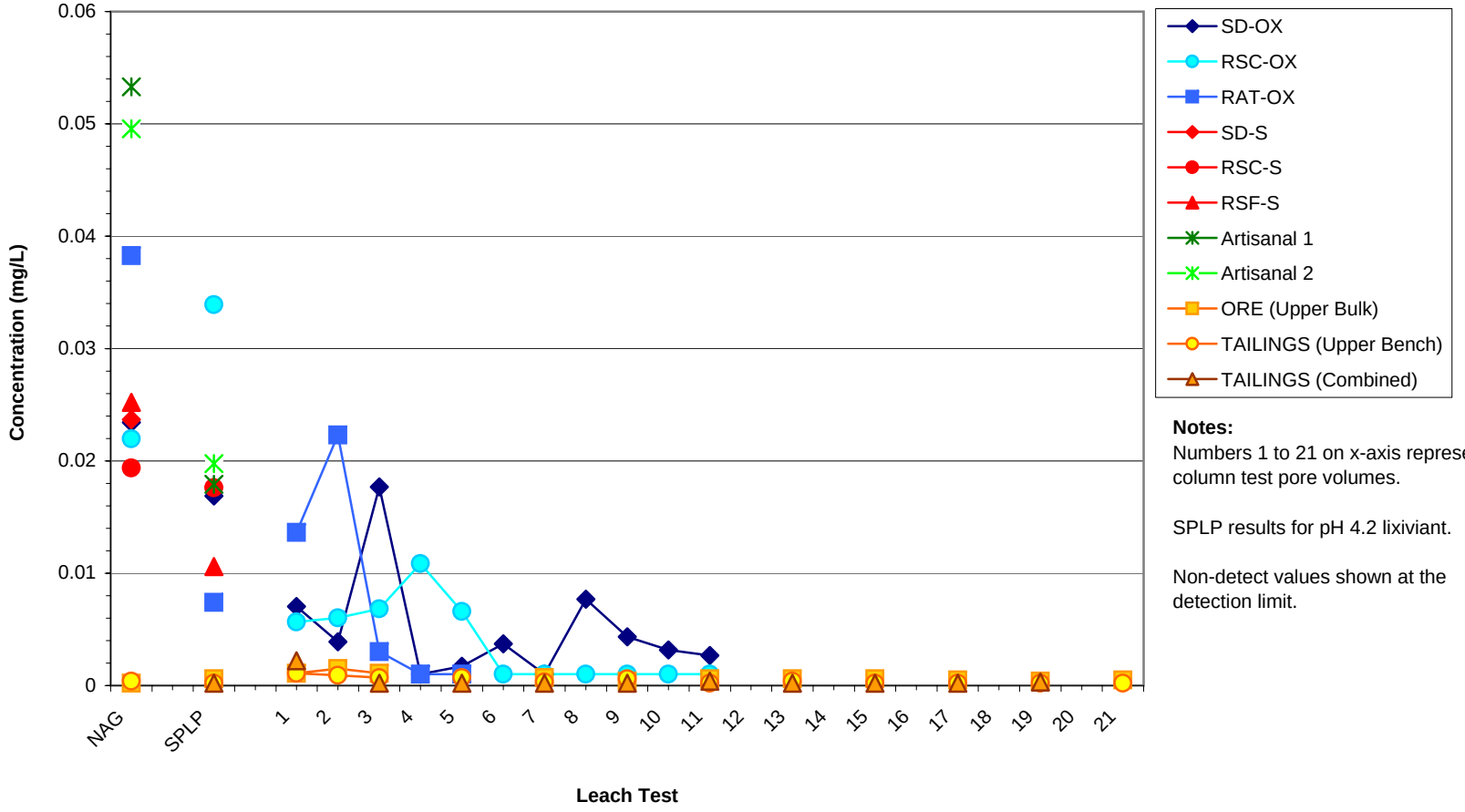
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Molybdenum

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-42**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

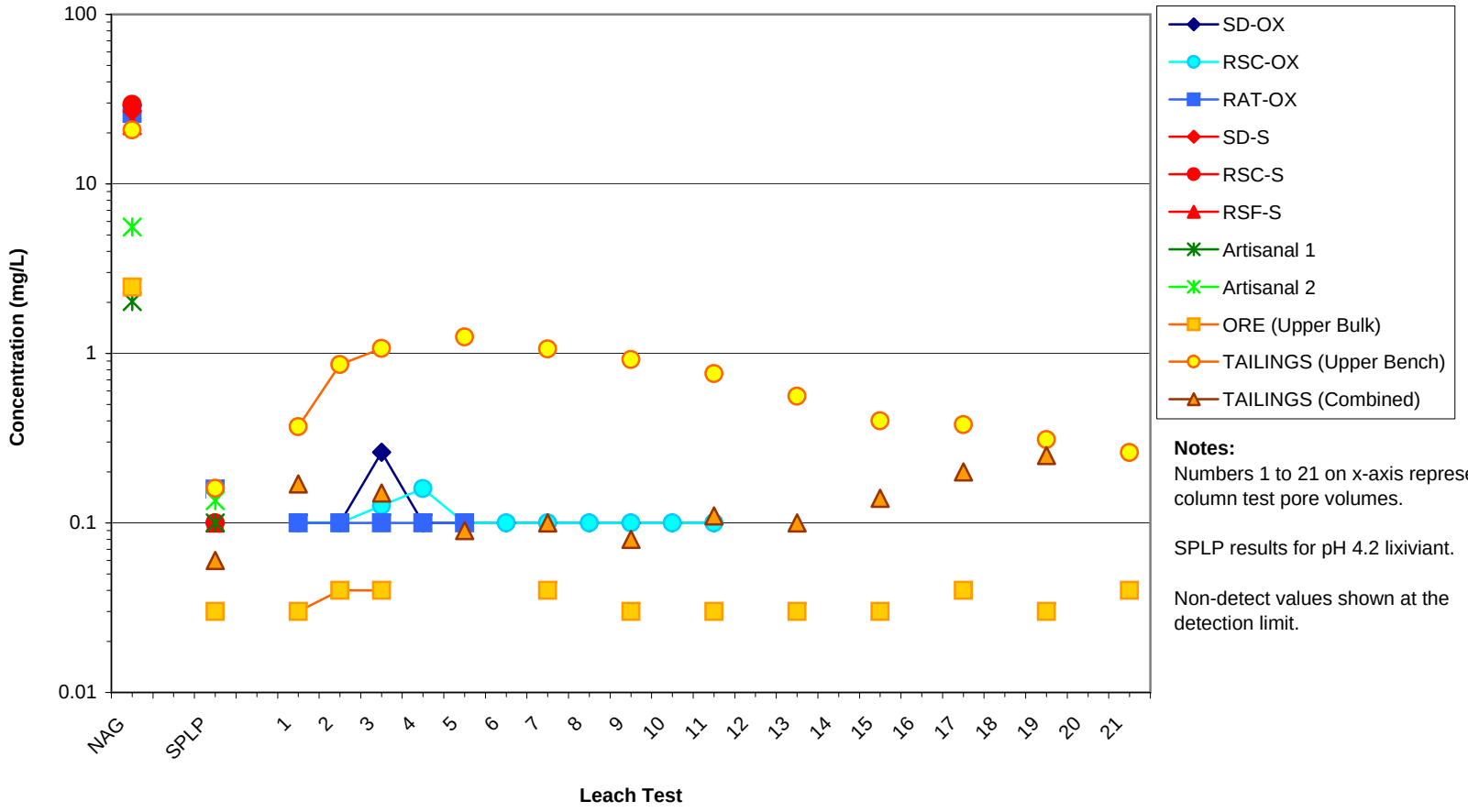
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Nickel

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-43**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

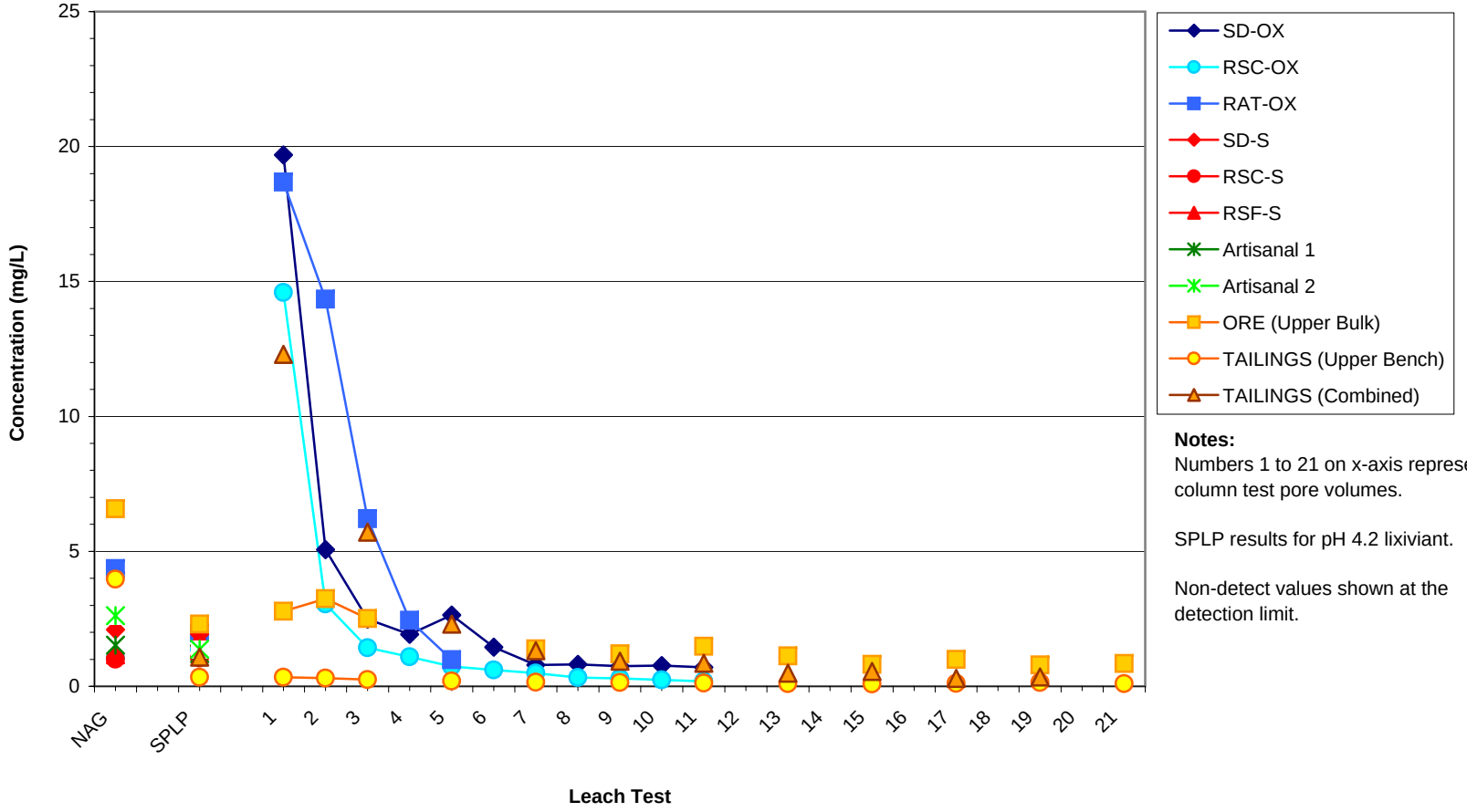
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Phosphorus

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-44**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

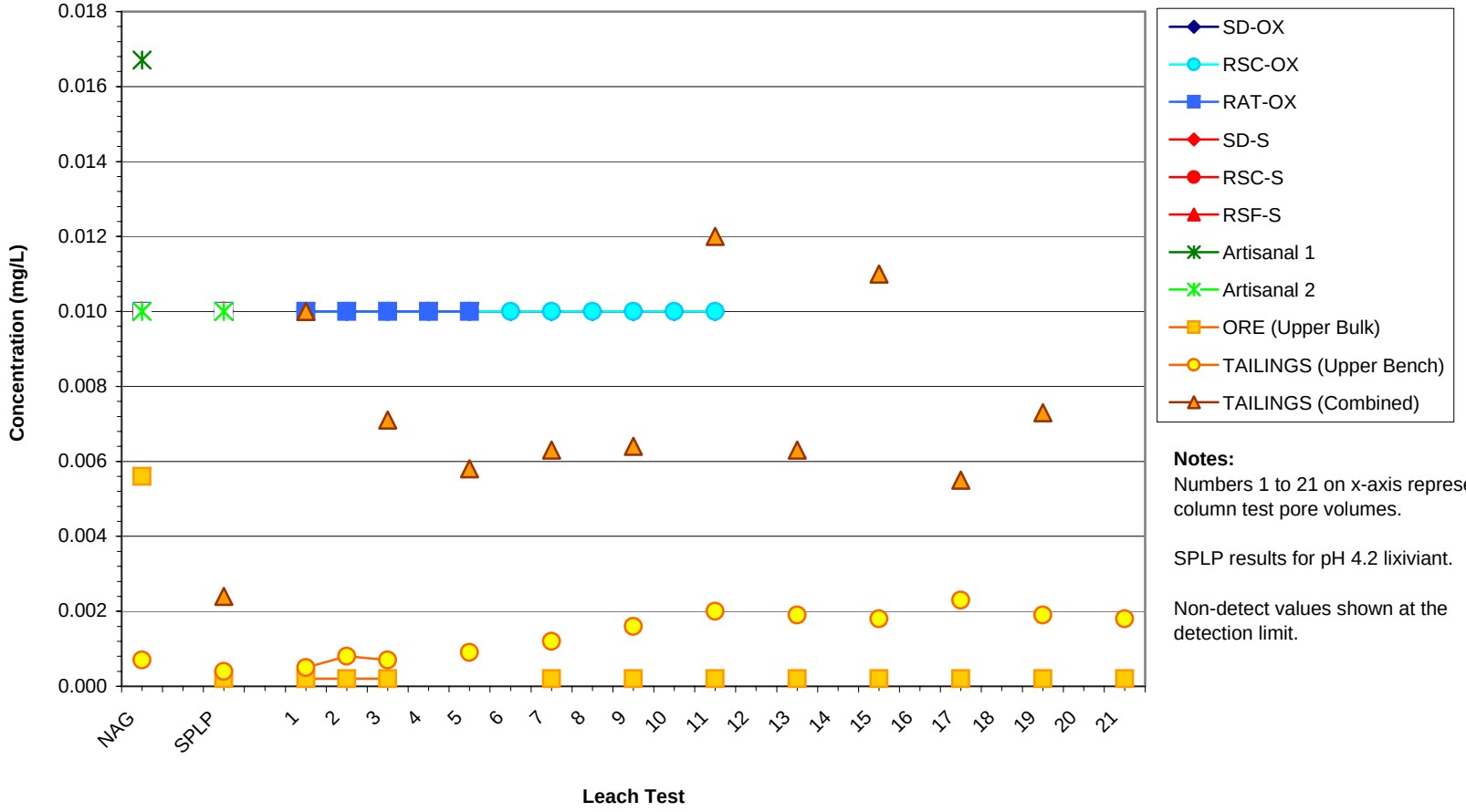
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Potassium

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-45**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

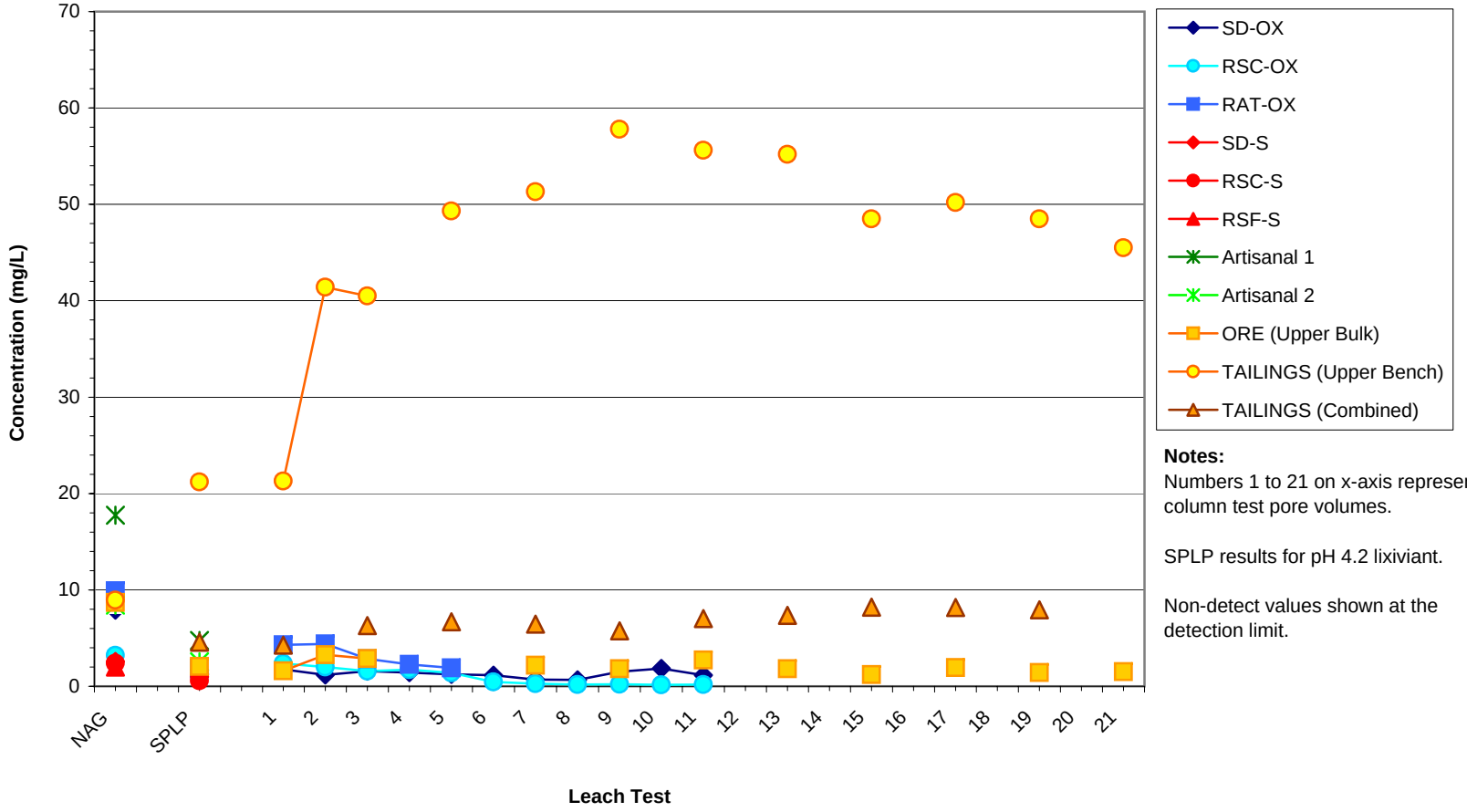
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Selenium

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-46**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

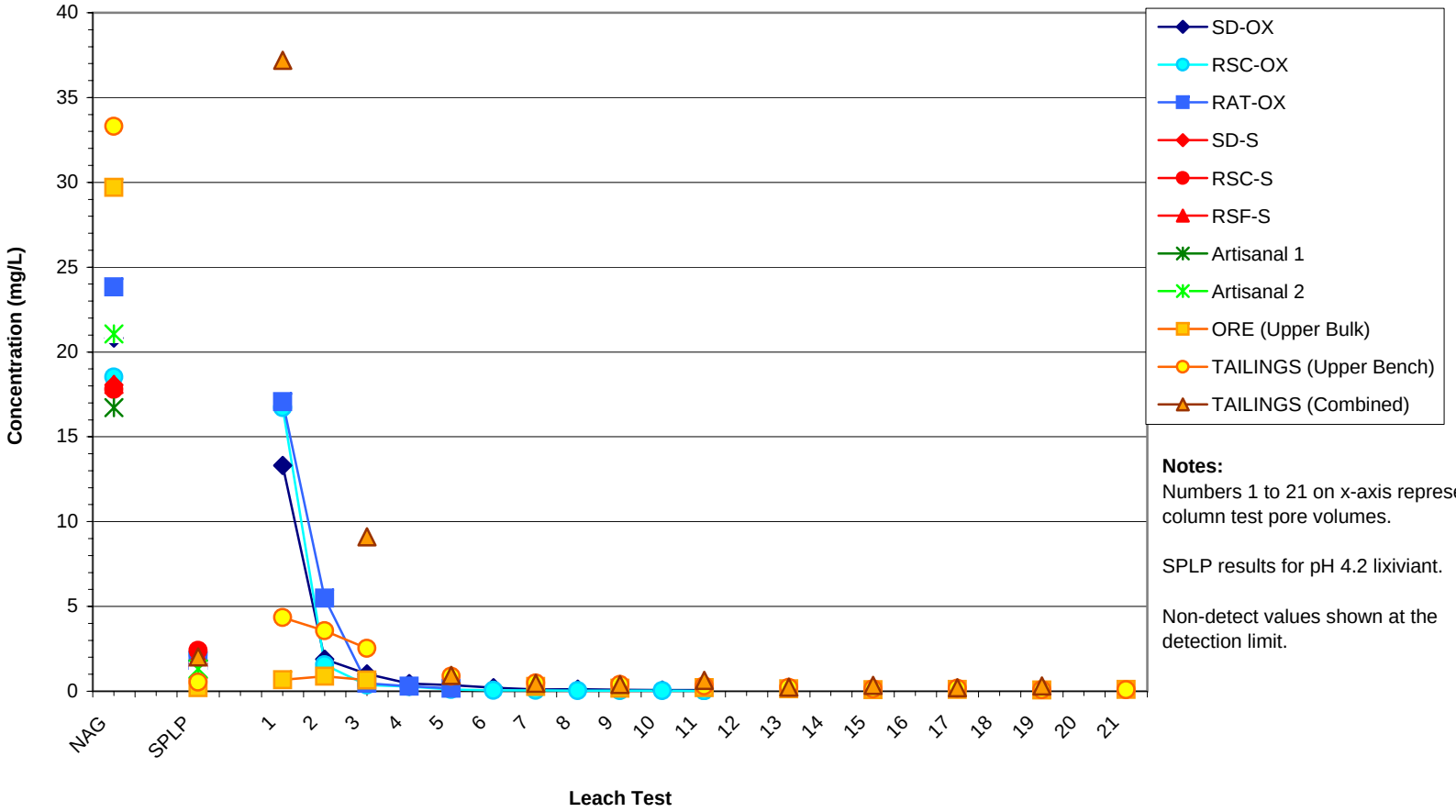
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Silicon

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-47**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

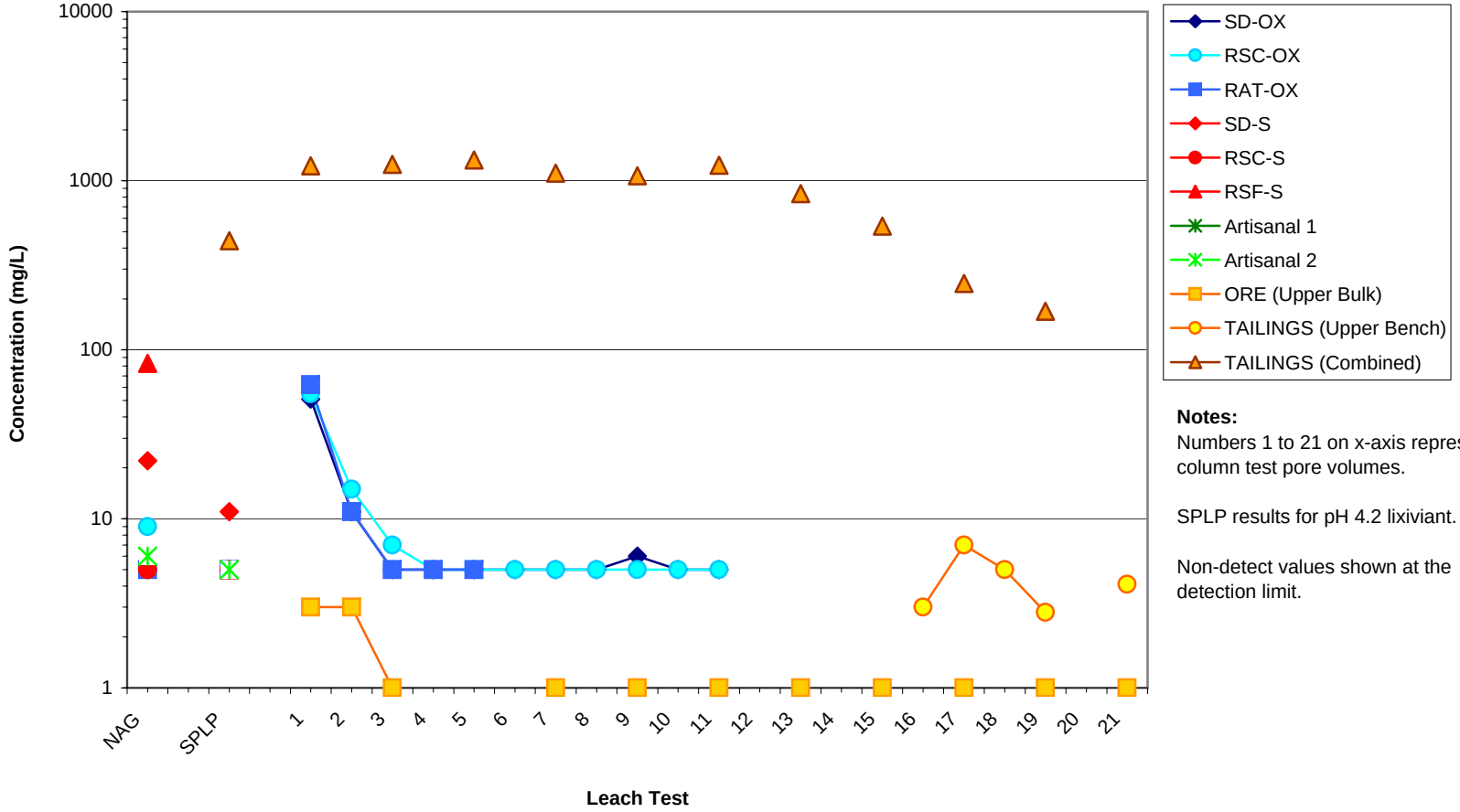
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Sodium

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-48**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

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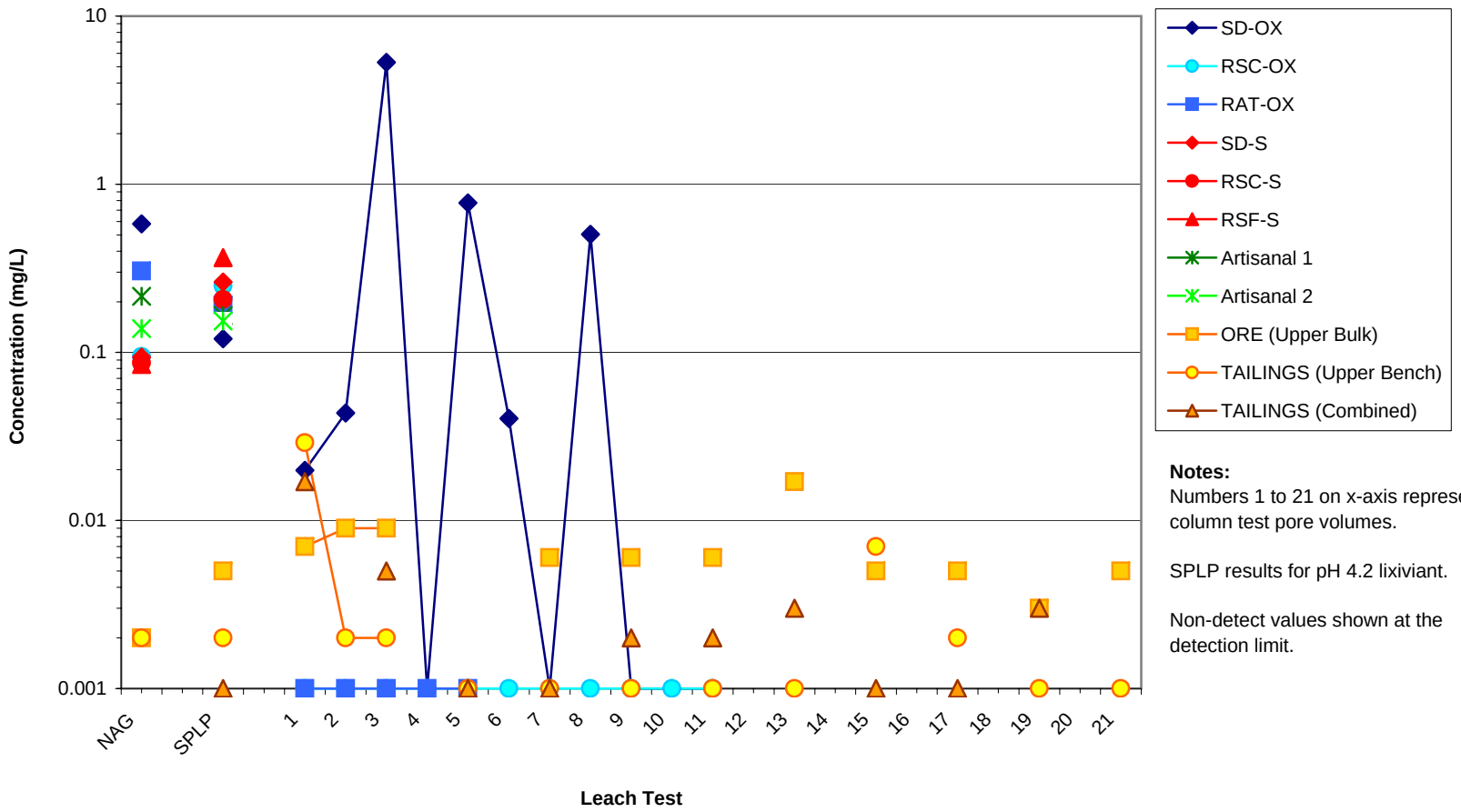
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Sulfate

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-49**



Notes:
Numbers 1 to 21 on x-axis represent column test pore volumes.

SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

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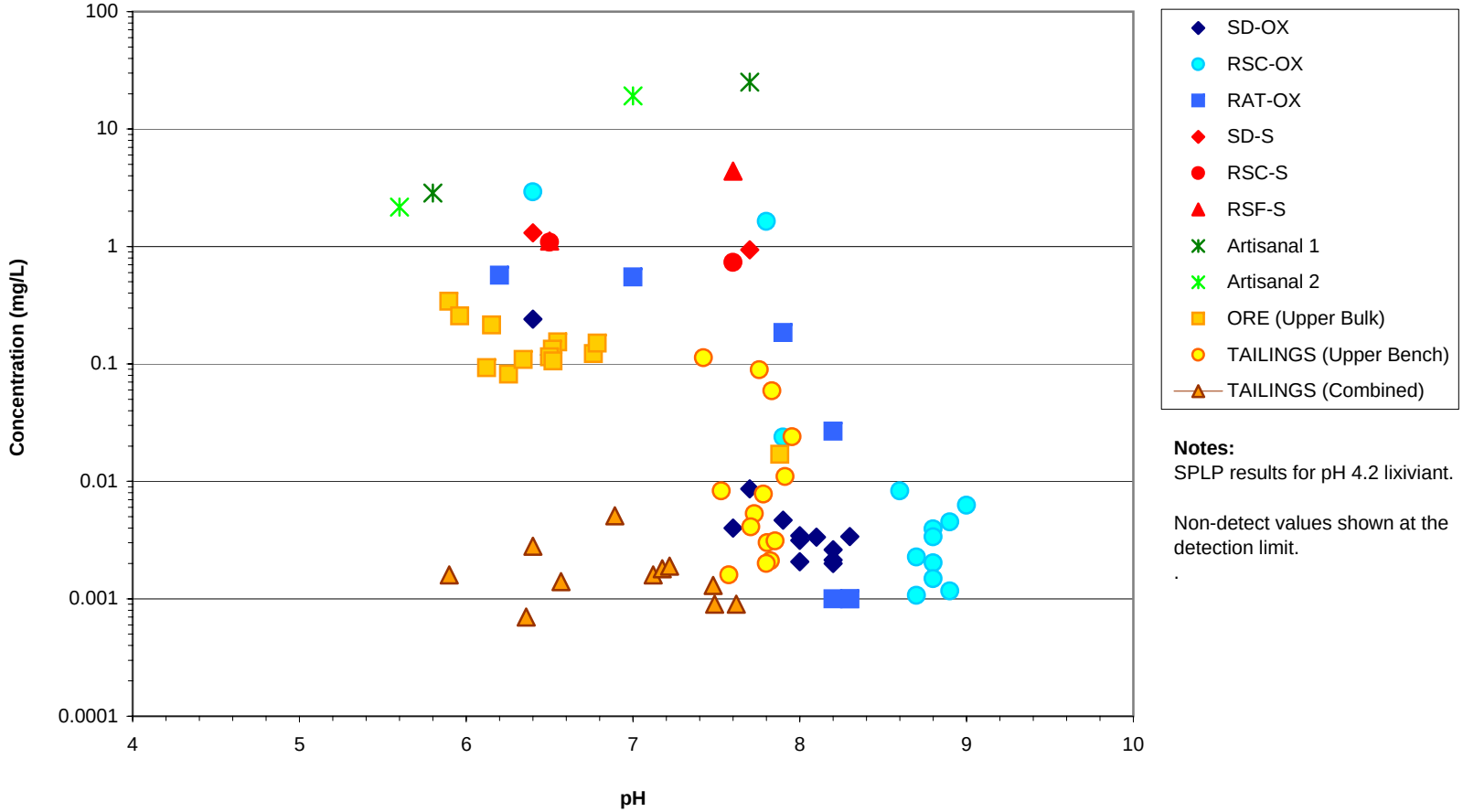
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Zinc

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-50**



Notes:
SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.
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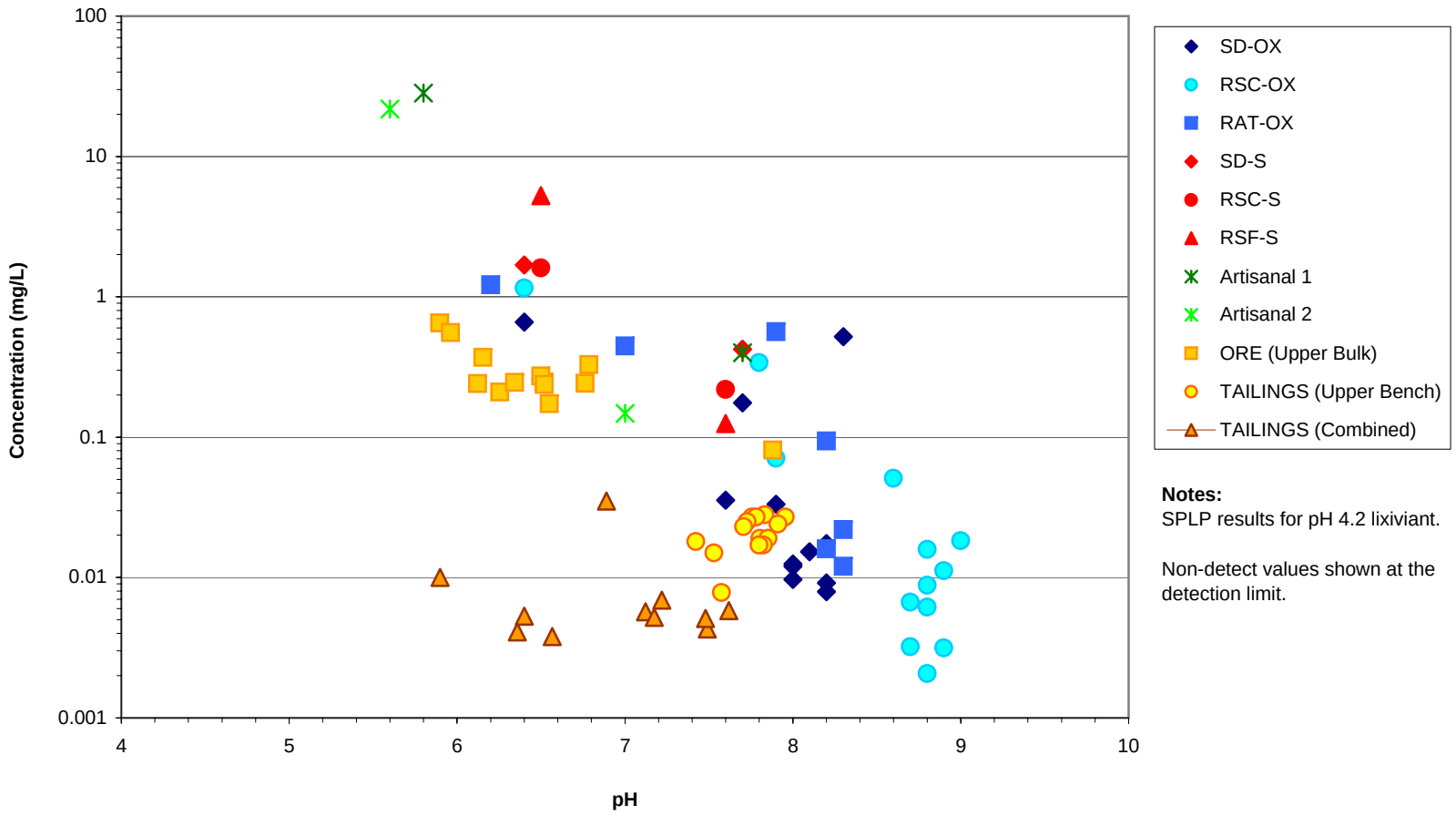
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Cobalt vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-51**



Notes:
SPLP results for pH 4.2 lixiviant.

Non-detect values shown at the detection limit.

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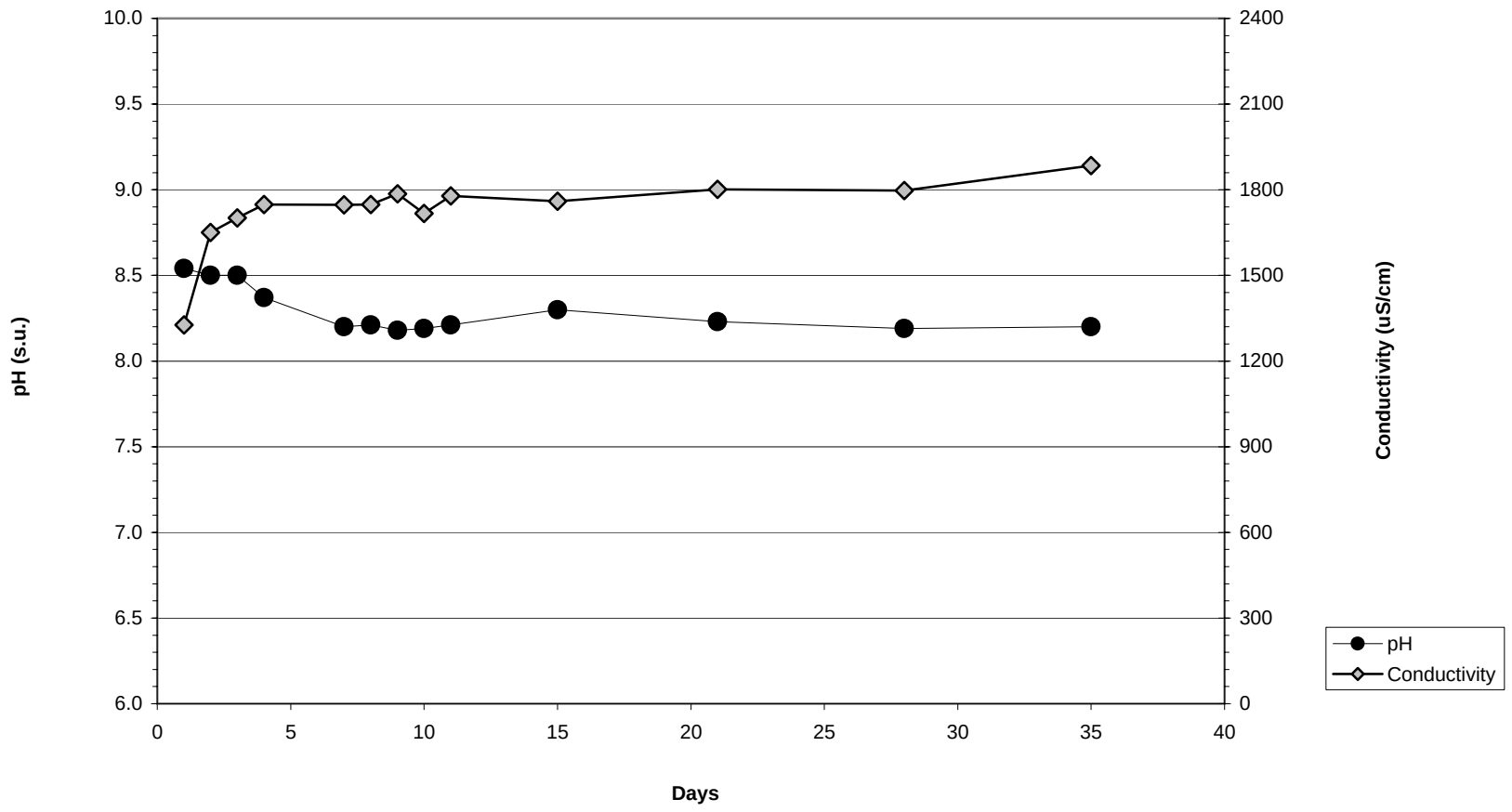
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

NAG, SPLP and Column Leach Test Results - Copper vs. pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Leach Figures (Mar 07).xls	FIGURE NO.	**5.4-52**



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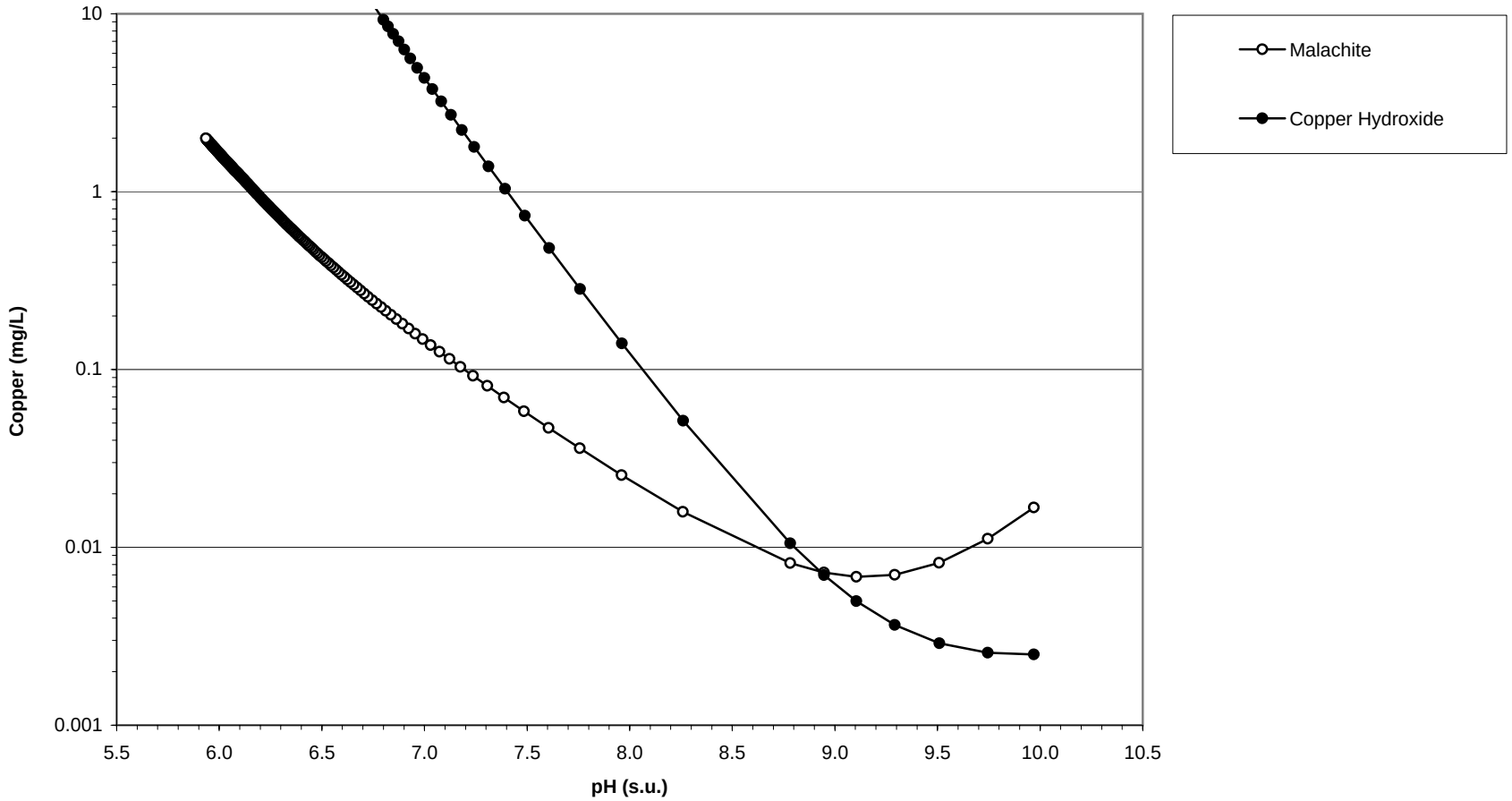
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Supernatant Stability Test Results

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334.035
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Stability (Mar 07).xls	FIGURE NO.	**5.6-1**



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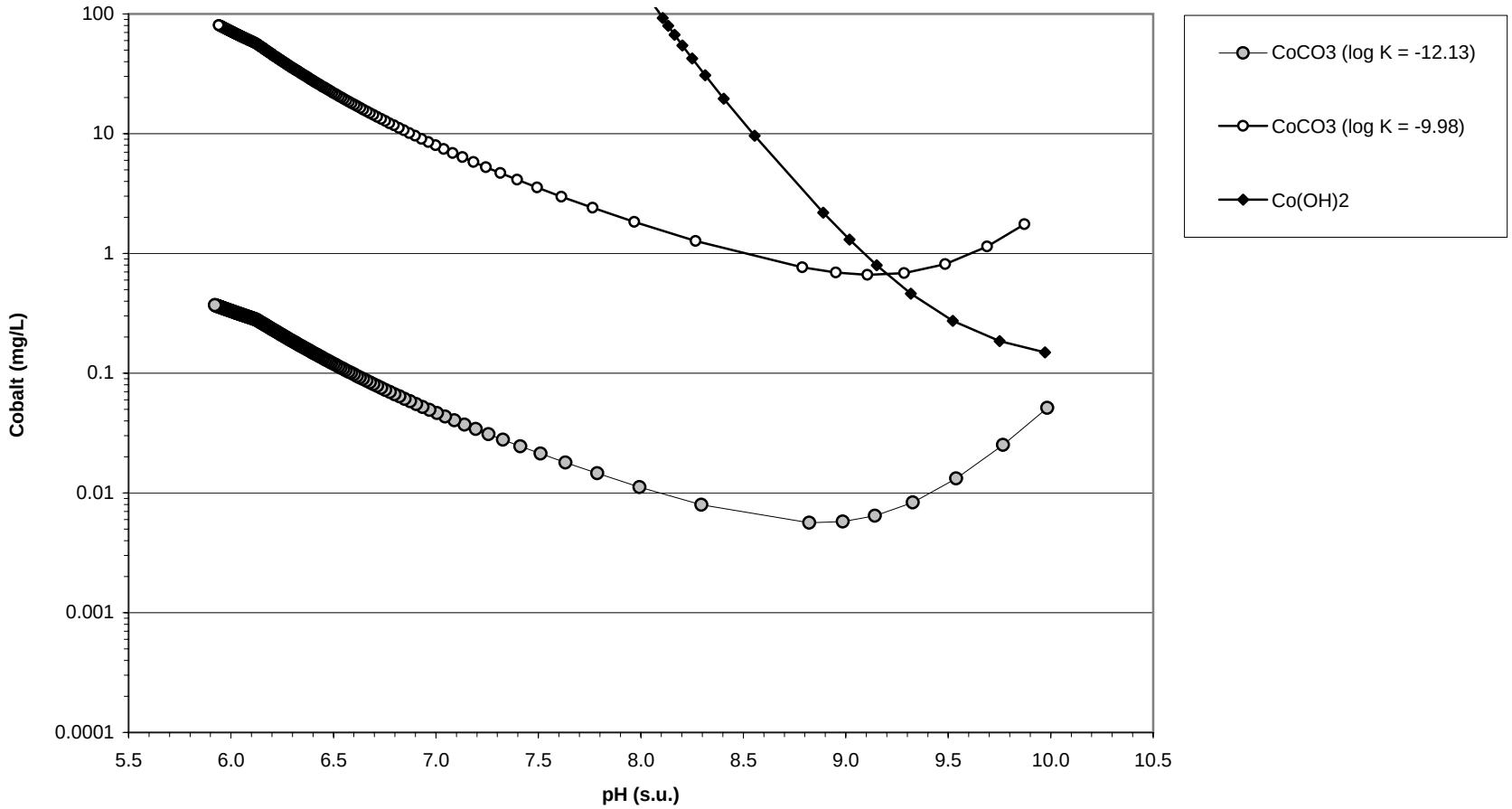
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Copper Mineral Solubility Curves

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Solubility Controls (v12) (Mar 07).xls	FIGURE NO.	**6.1-1**



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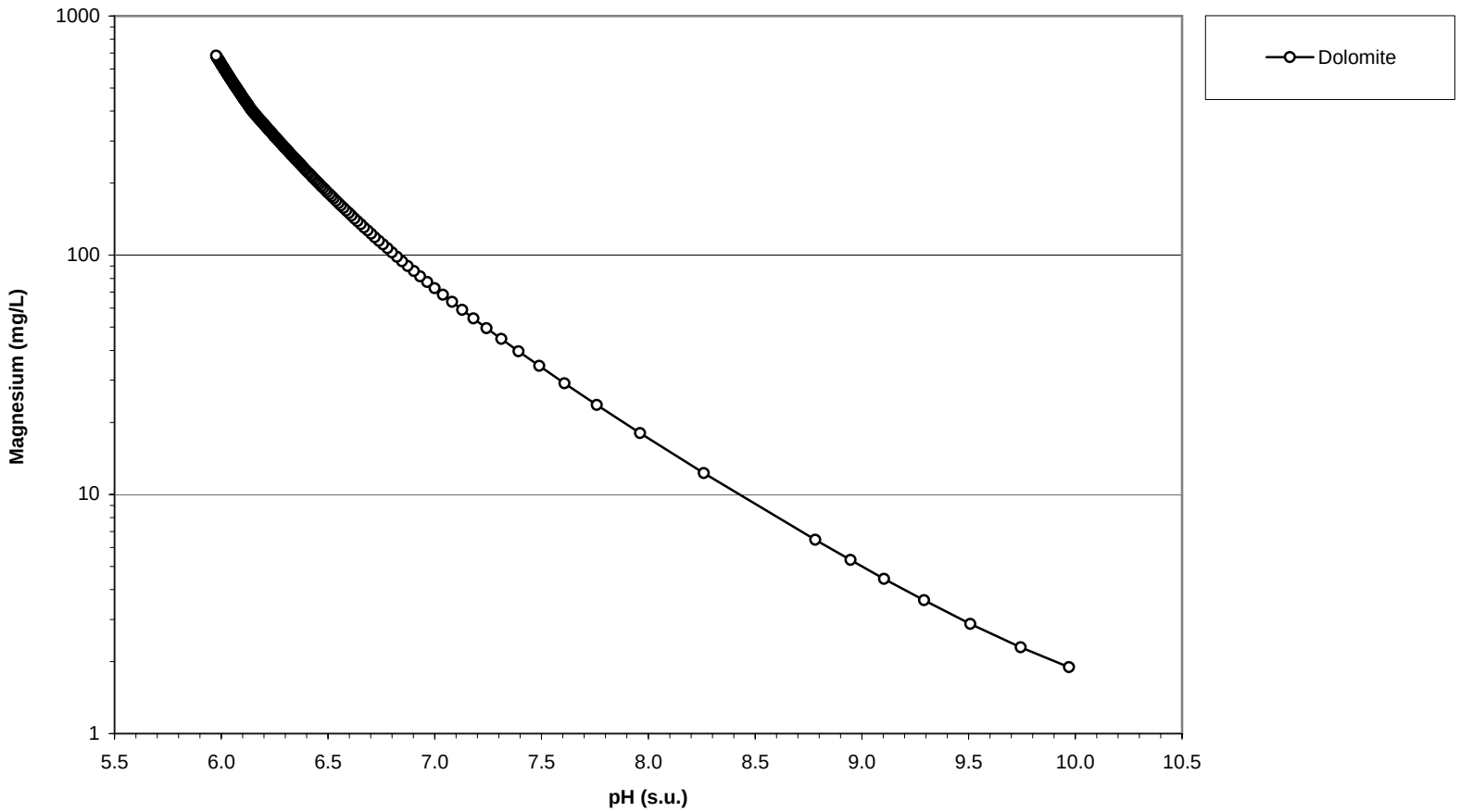
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Cobalt Mineral Solubility Curves

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Solubility Controls (v12) (Mar 07).xls	FIGURE NO.	**6.1-2**



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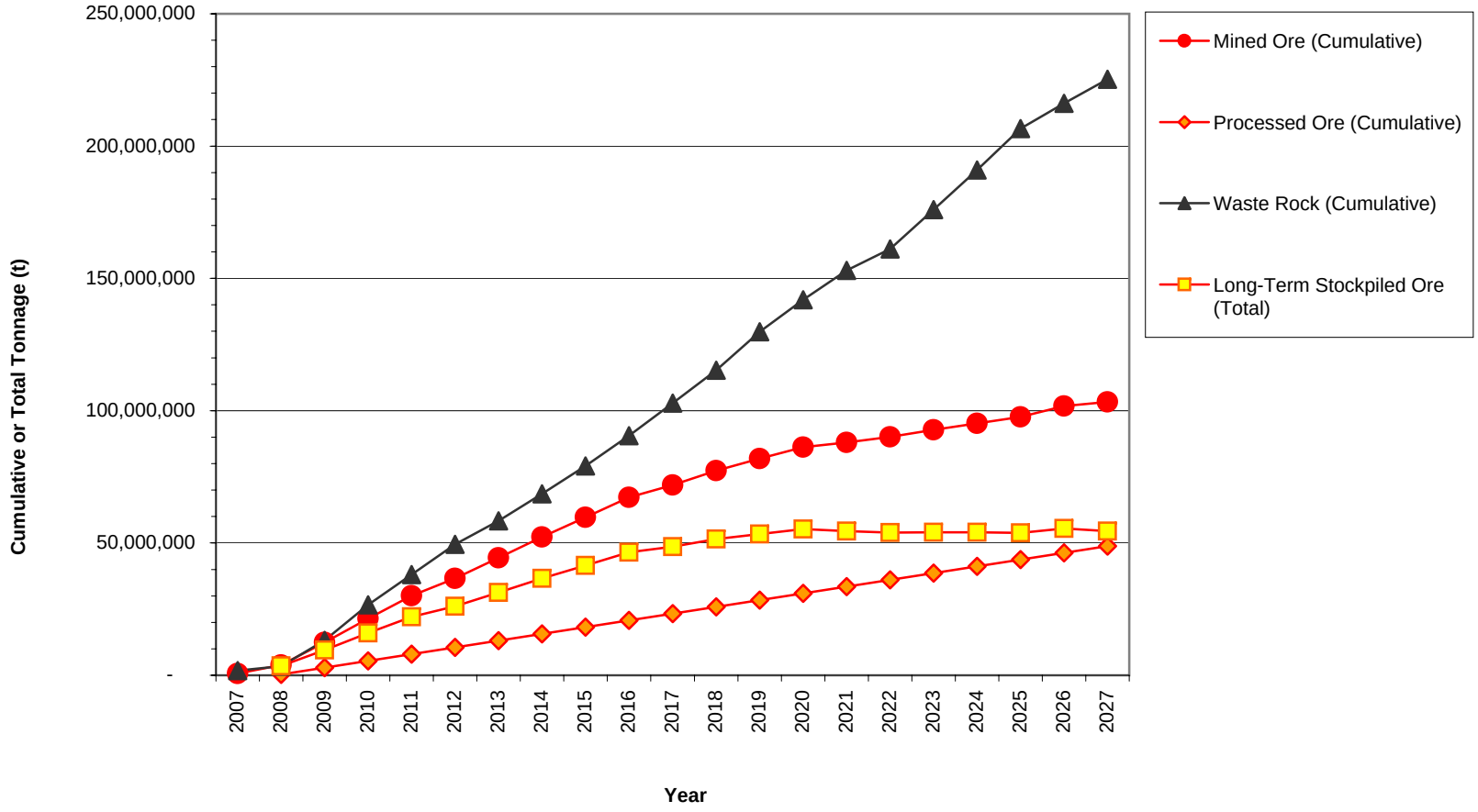
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Dolomite Solubility Curve

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Solubility Controls (v12) (Mar 07).xls	FIGURE NO.	6.1-3



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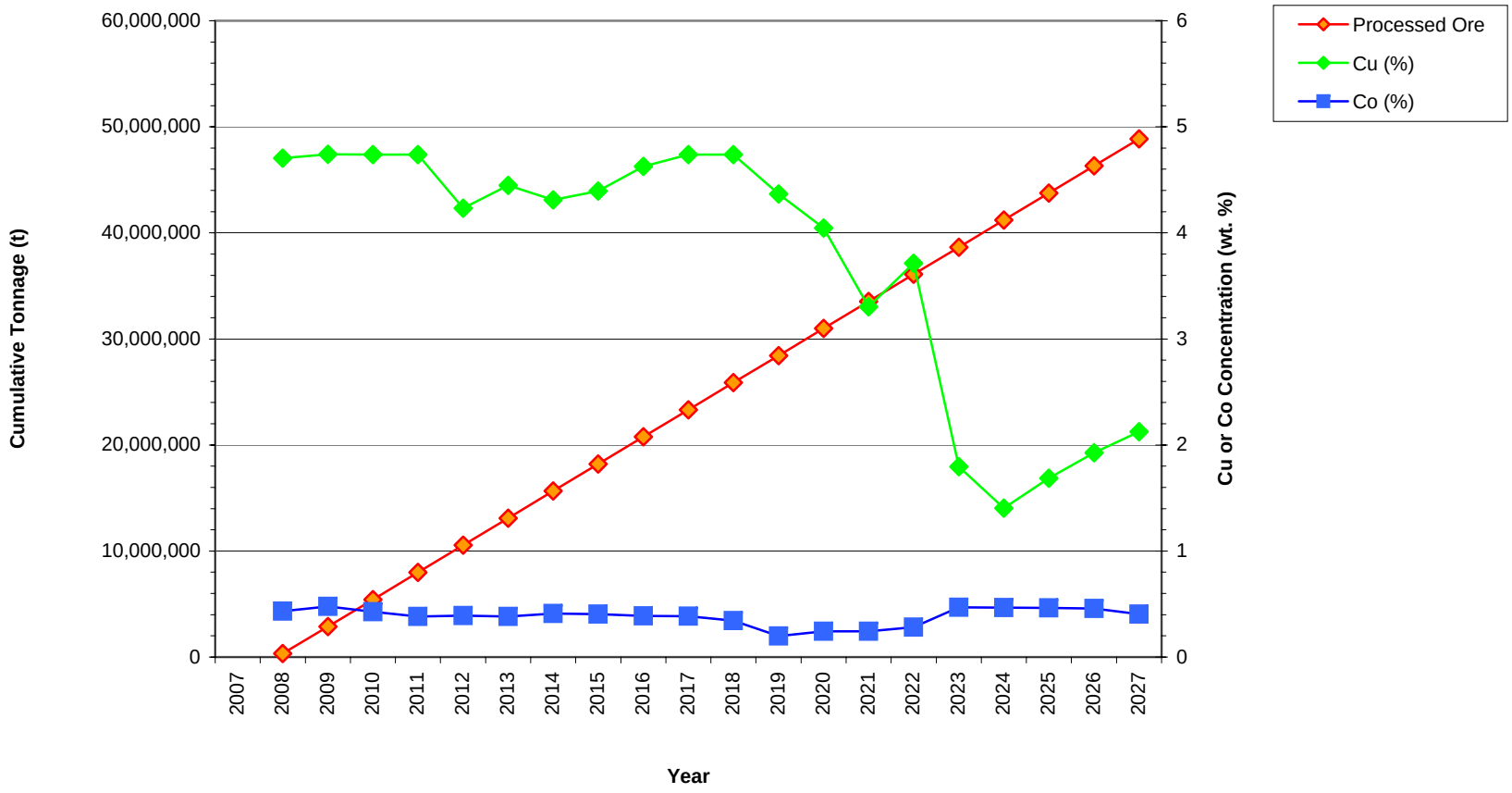
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Waste Rock and Ore Tonnages (2007 to 2027)

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	File No	Tenke - WR and Stockpile Size (Mar 07).xls	FIGURE NO.	**6.1-4**



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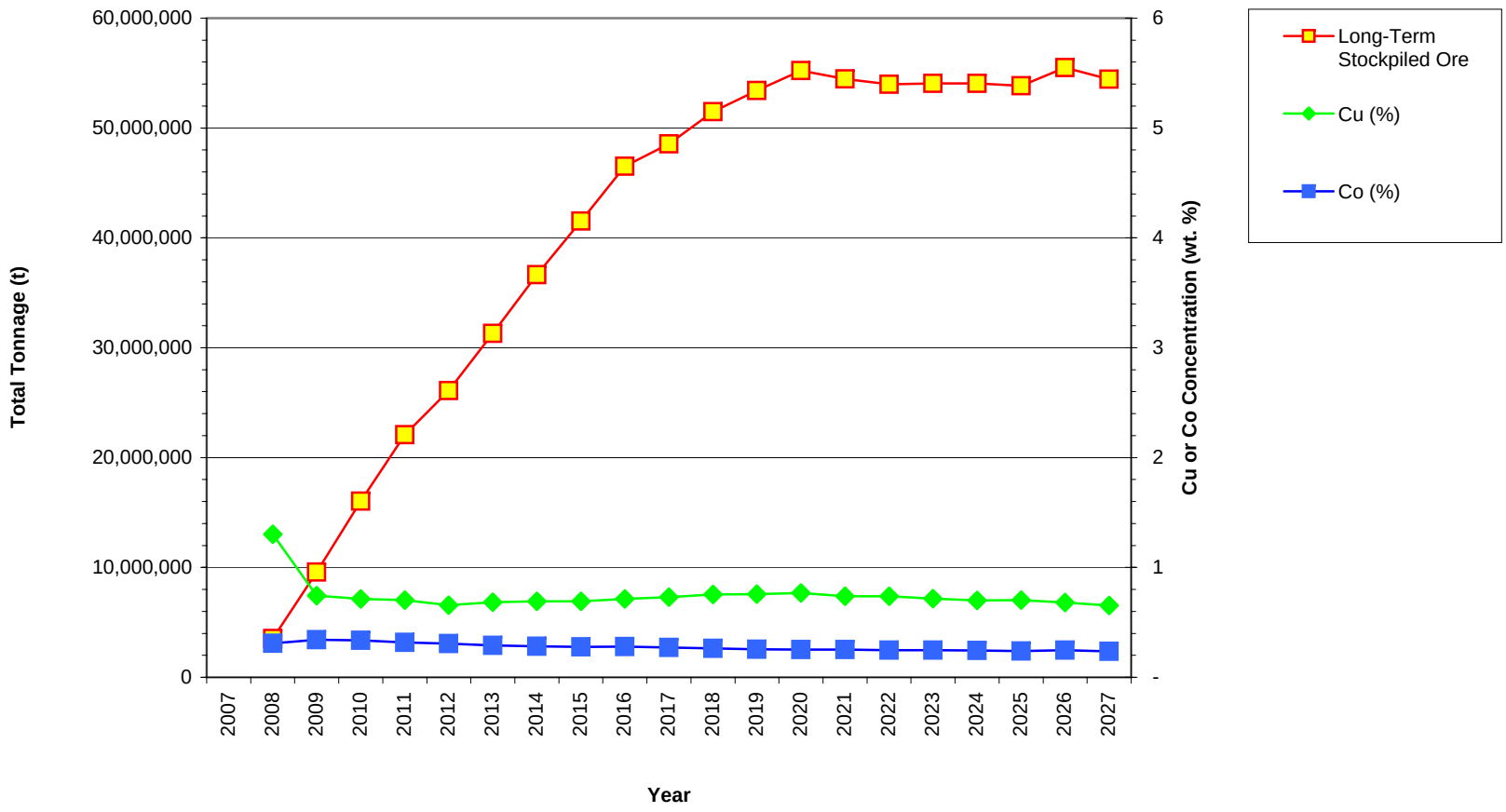
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Short-Term ROM Ore Stockpiles Copper and Cobalt Grades

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	File No.	Tenke - WR and Stockpile Size (Mar 07).xls	FIGURE NO.	**6.3-1**



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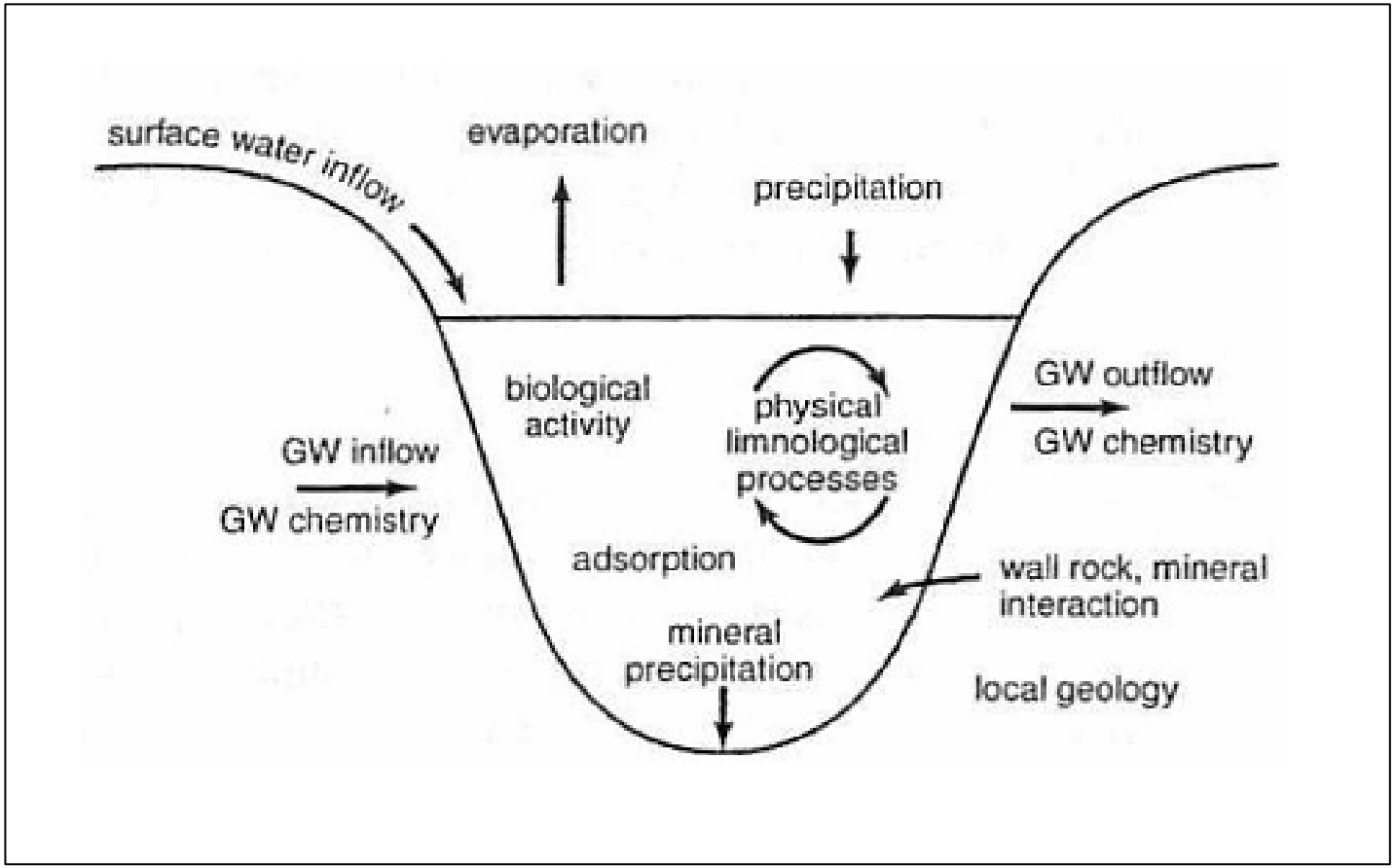
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Long-Term Ore Stockpiles Copper and Cobalt Grades

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	File No.	Tenke - WR and Stockpile Size (Mar 07).xls	FIGURE NO.	**6.3-2**



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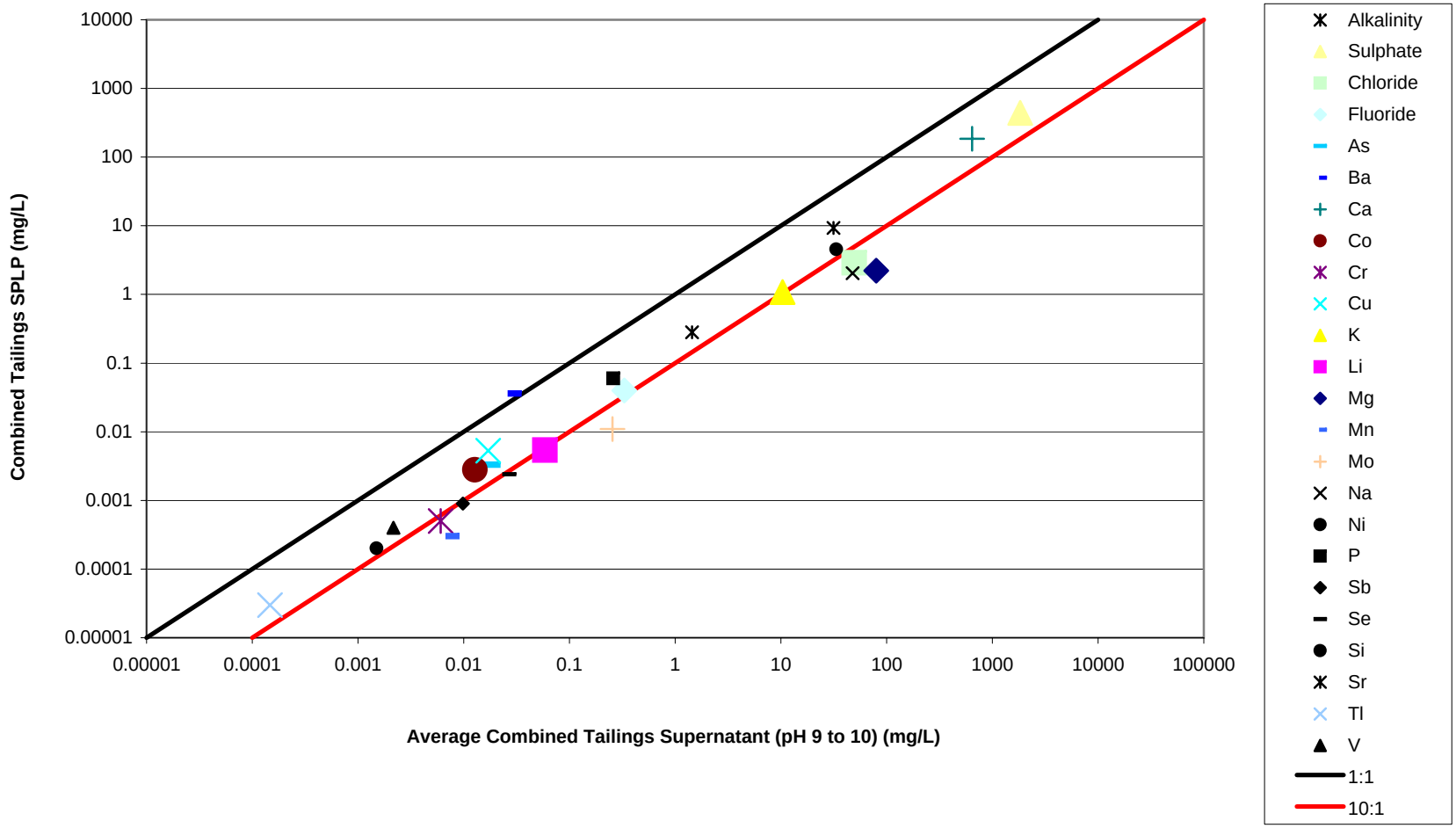
Conceptual Model of a Mine Pit Lake (Tempel et. al., 2000)

Tenke Fungurume Mining S.A.R.L. (TFM)

DRAWN	na	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	KG	SCALE	na	DWG. NO.	
REVIEWED	NB	FILE NO.	Tenke - Pit Figures (Mar 07).xls	FIGURE NO.	**6.4-1**



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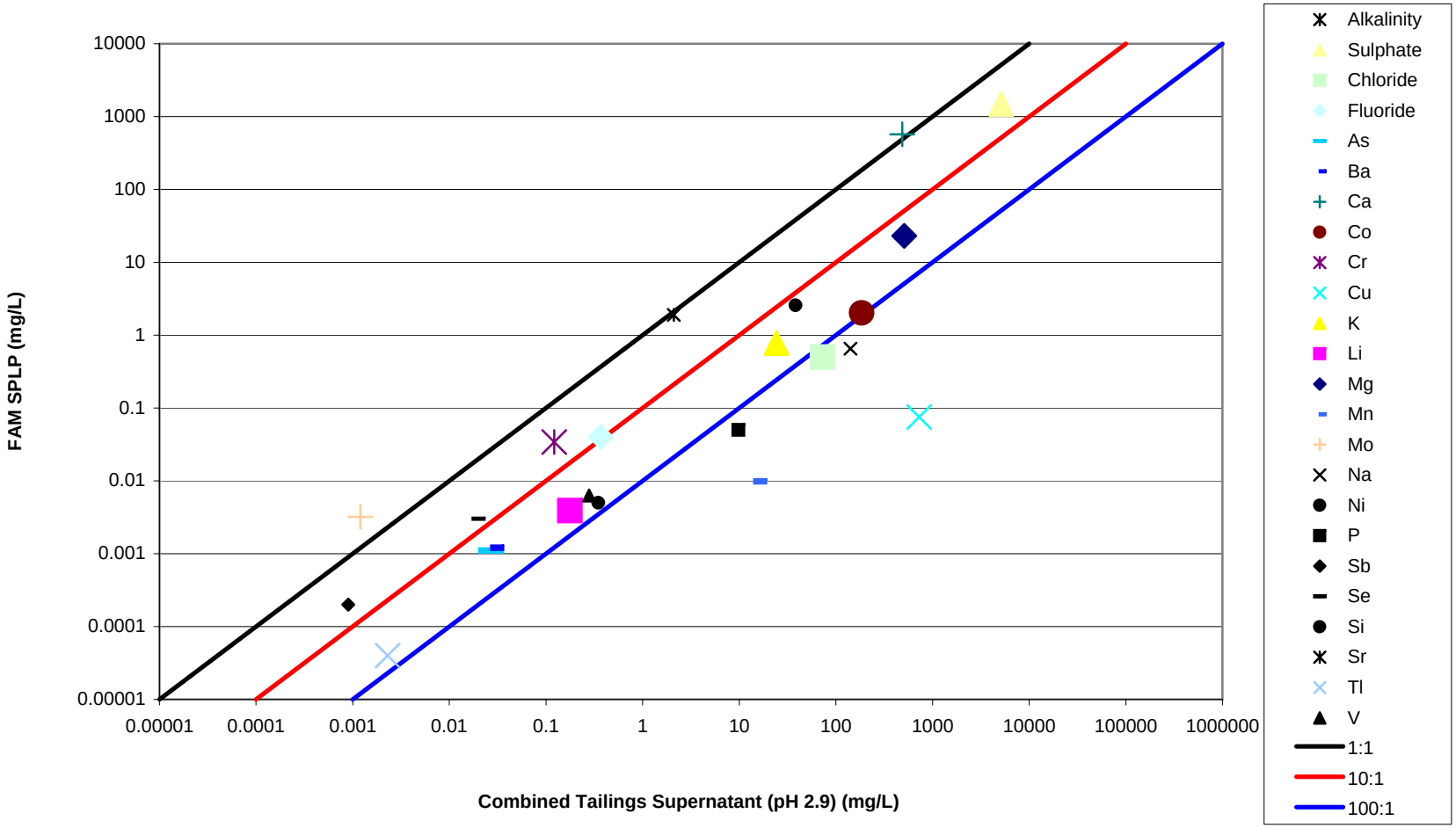
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Combined Tailings Leach Test Results

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 31Ha (V2).xls	FIGURE NO.	**6.5-1**



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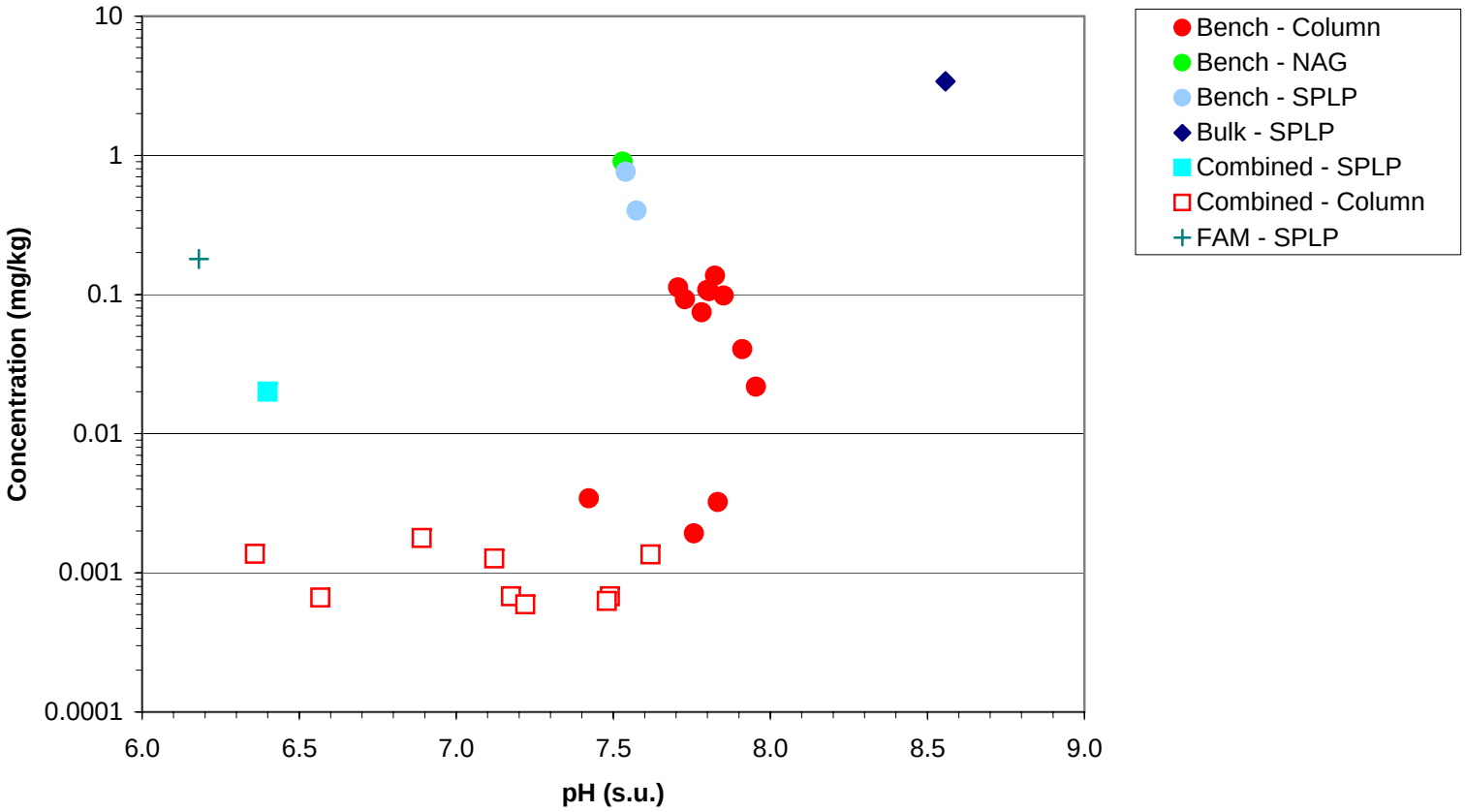
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

FAM SPLP Leachate and Combined Tailings Supernatant Pre-Neutralization

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 31Ha (V2).xls	FIGURE NO.	6.5-2



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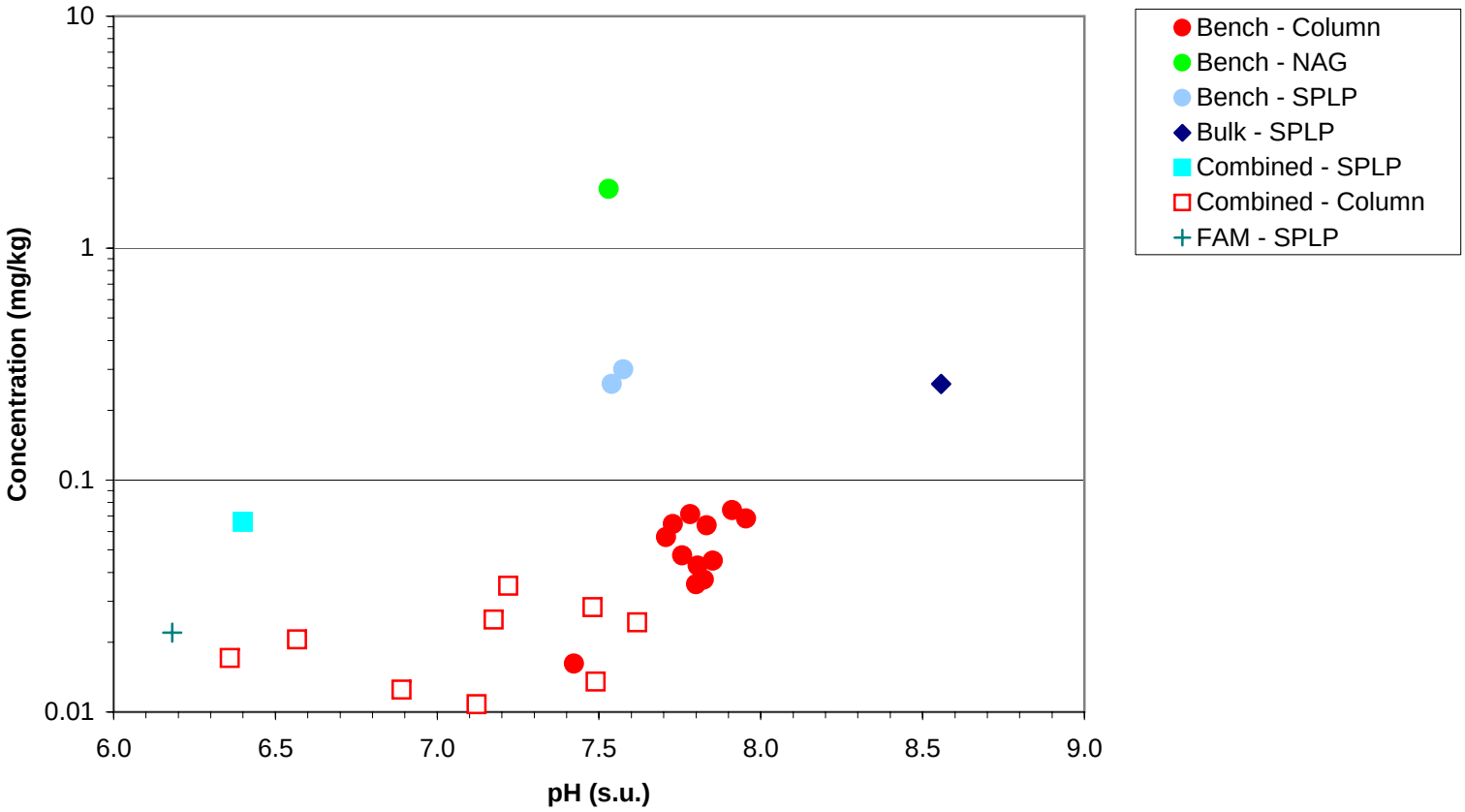
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Characterization - Aluminum Leach Test Results

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Runoff (V2).xls	FIGURE NO.	**6.5-3**



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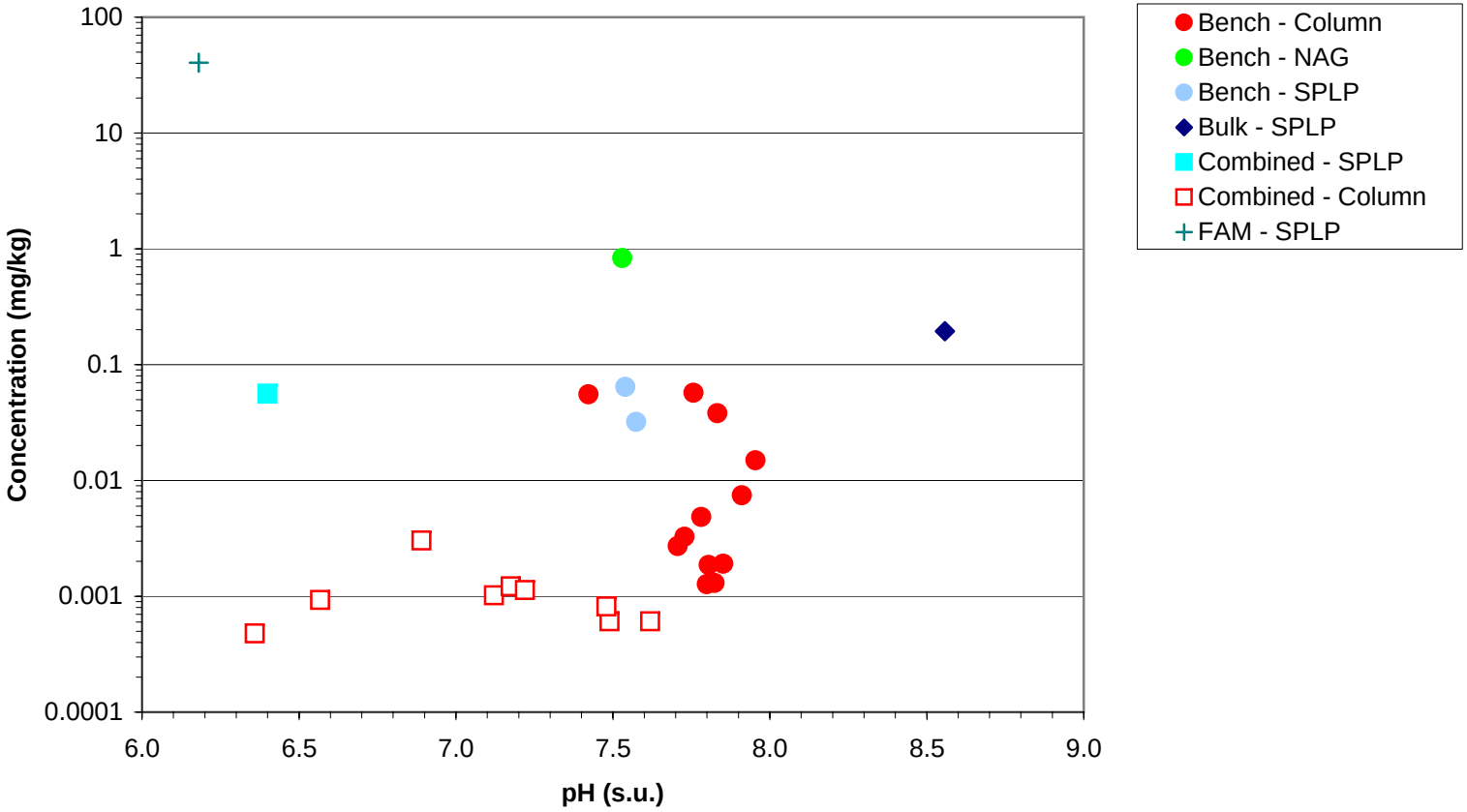
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Characterization - Arsenic Leach Test Results

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Runoff (V2).xls	FIGURE NO.	6.5-4



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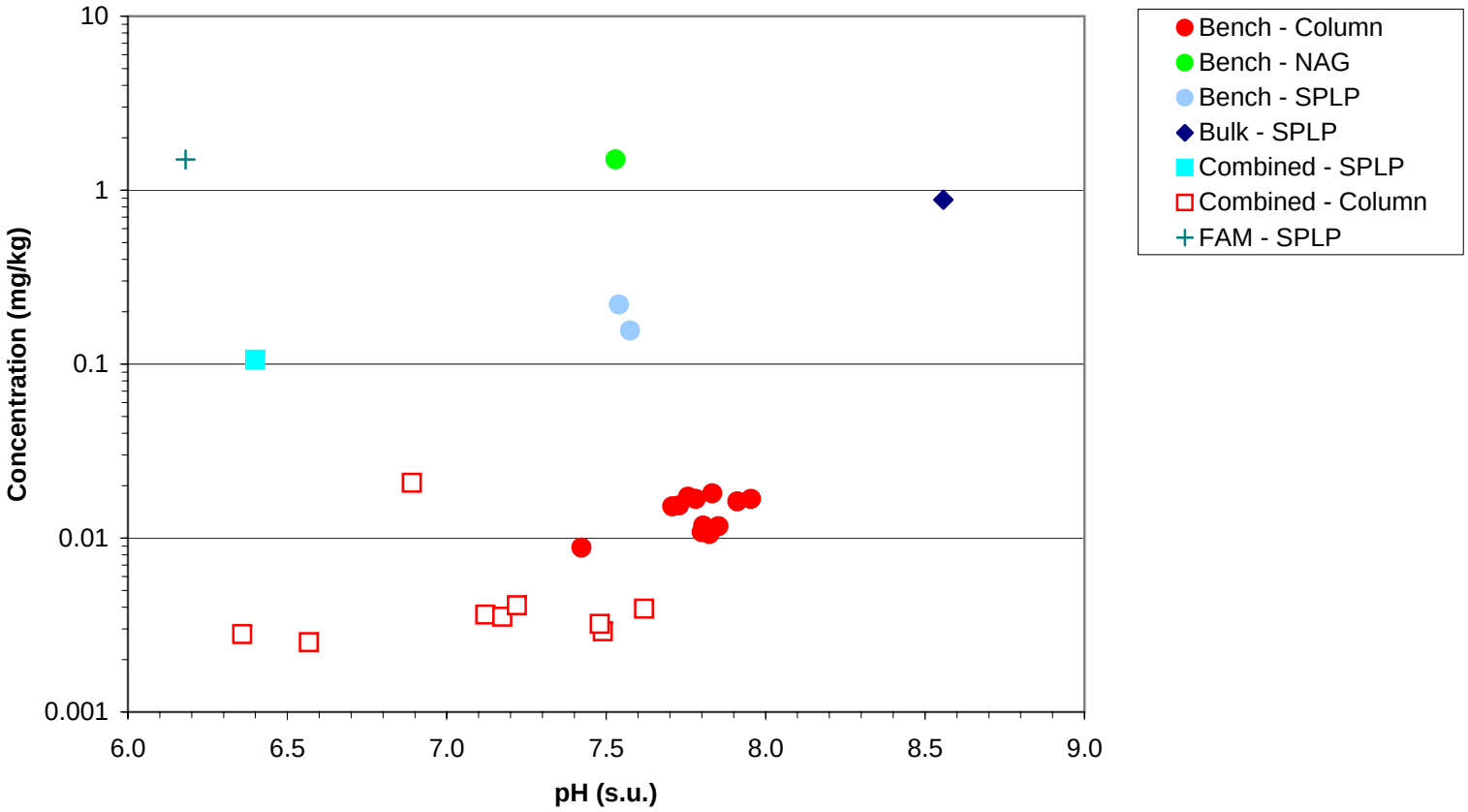
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Characterization - Cobalt Leach Test Results

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Runoff (V2).xls	FIGURE NO.	6.5-5



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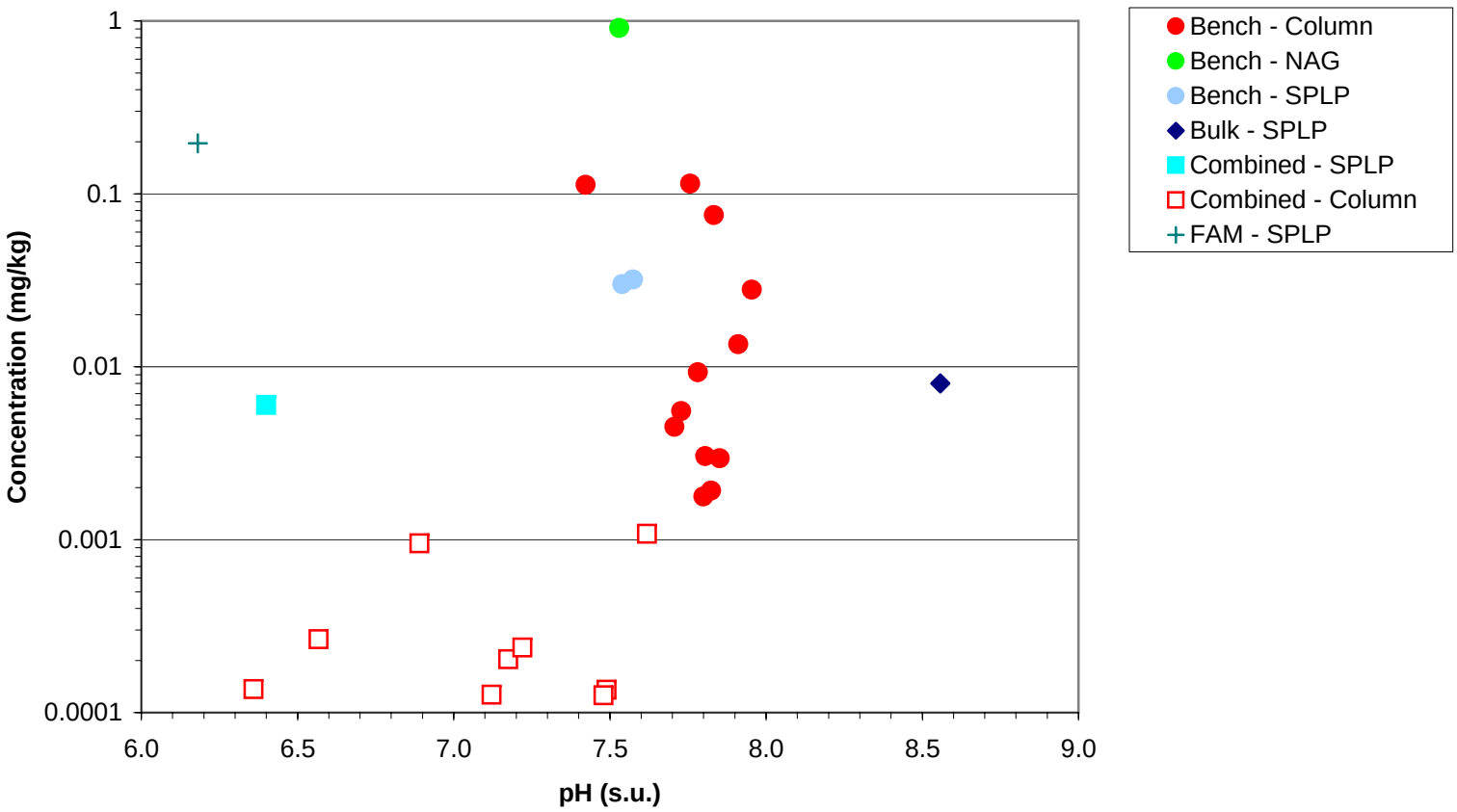
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Characterization - Copper Leach Test Results

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Runoff (V2).xls	FIGURE NO.	**6.5-6**



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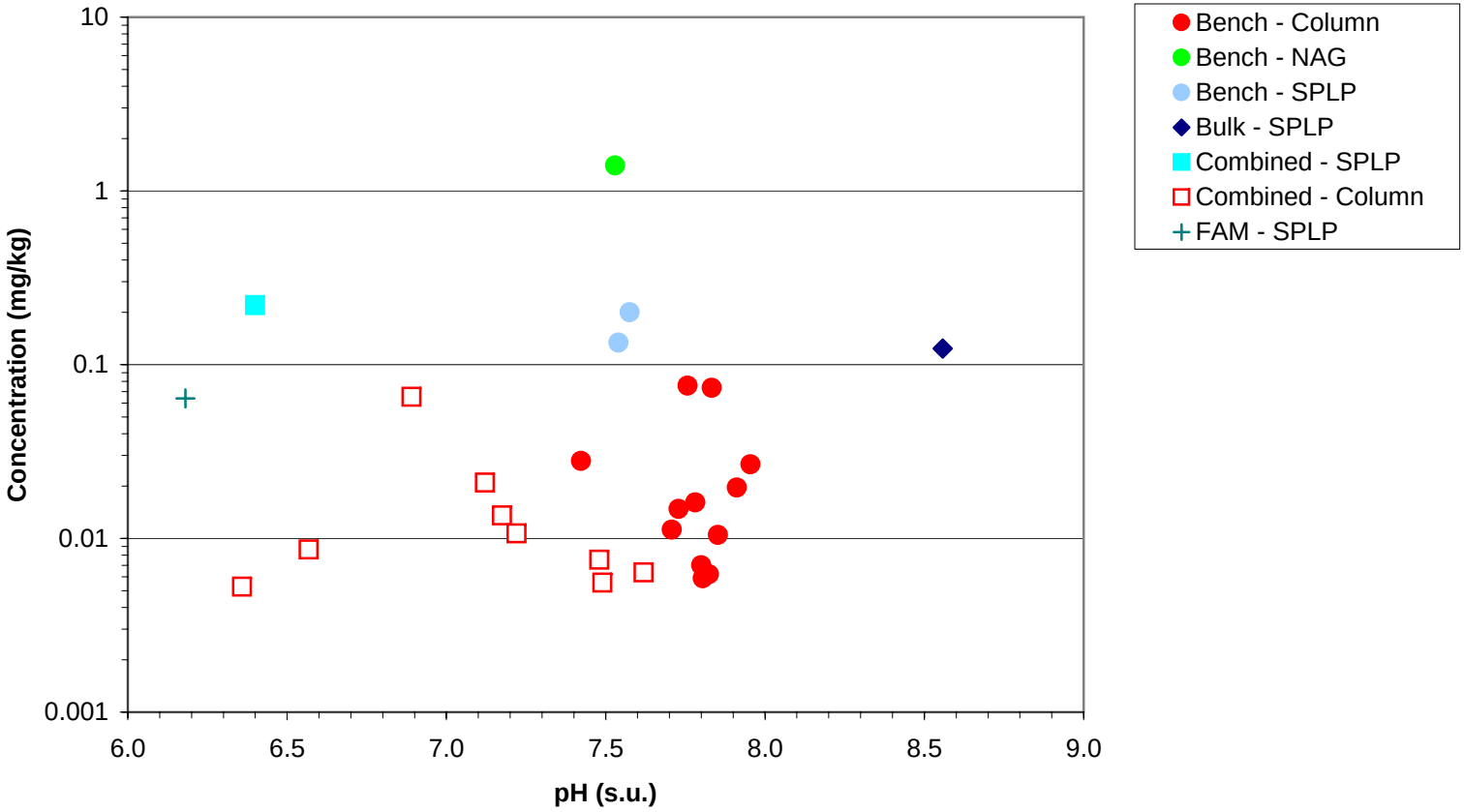
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Characterization - Manganese Leach Test Results

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Runoff (V2).xls	FIGURE NO.	6.5-7



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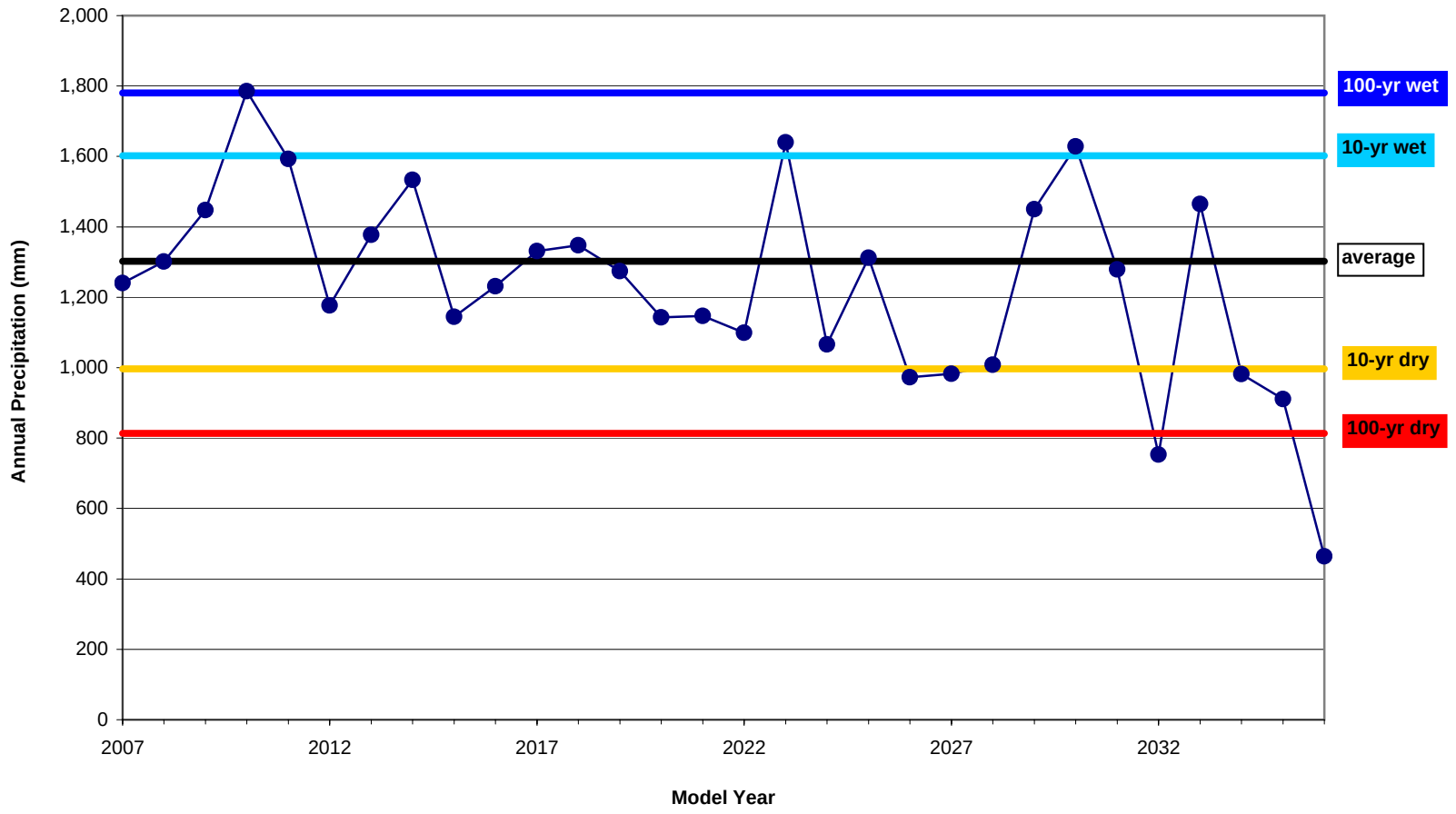
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Characterization - Molybdenum Leach Test Results

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Runoff (V2).xls	FIGURE NO.	6.5-8



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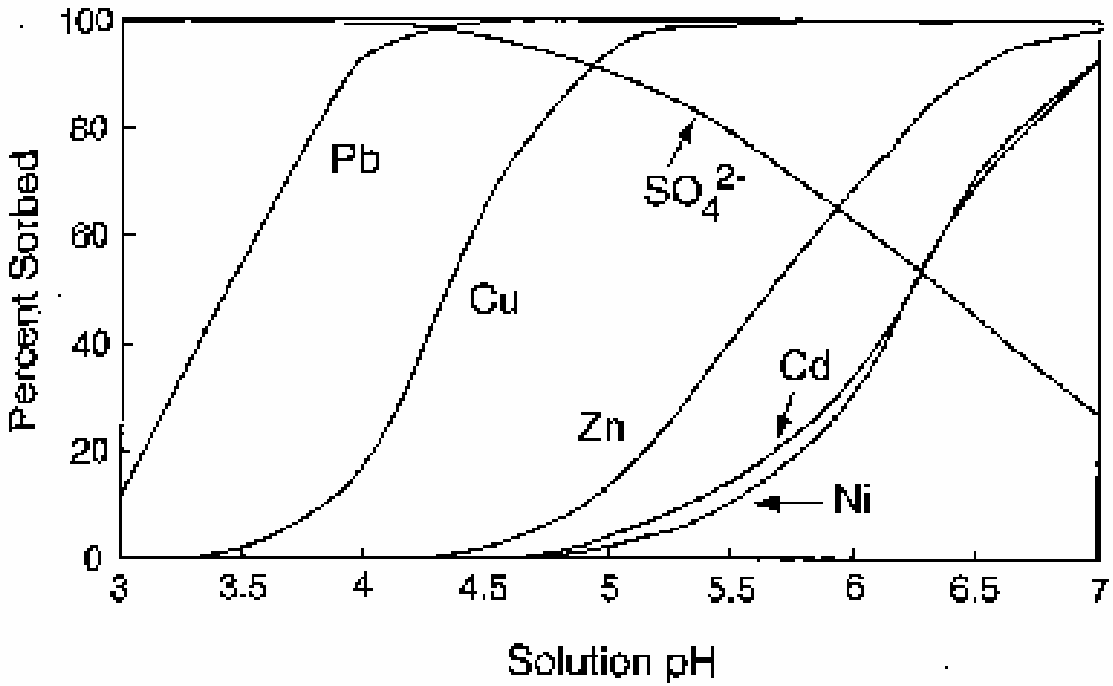
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Model Water Balance 30-year Precipitation Record

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Water Balance (V2).xls	FIGURE NO.	6.5-9



Notes:

Model sorption curves showing adsorption edges for metals and sulfate on hydrous ferric oxide.

Reproduced from Smith (1999).

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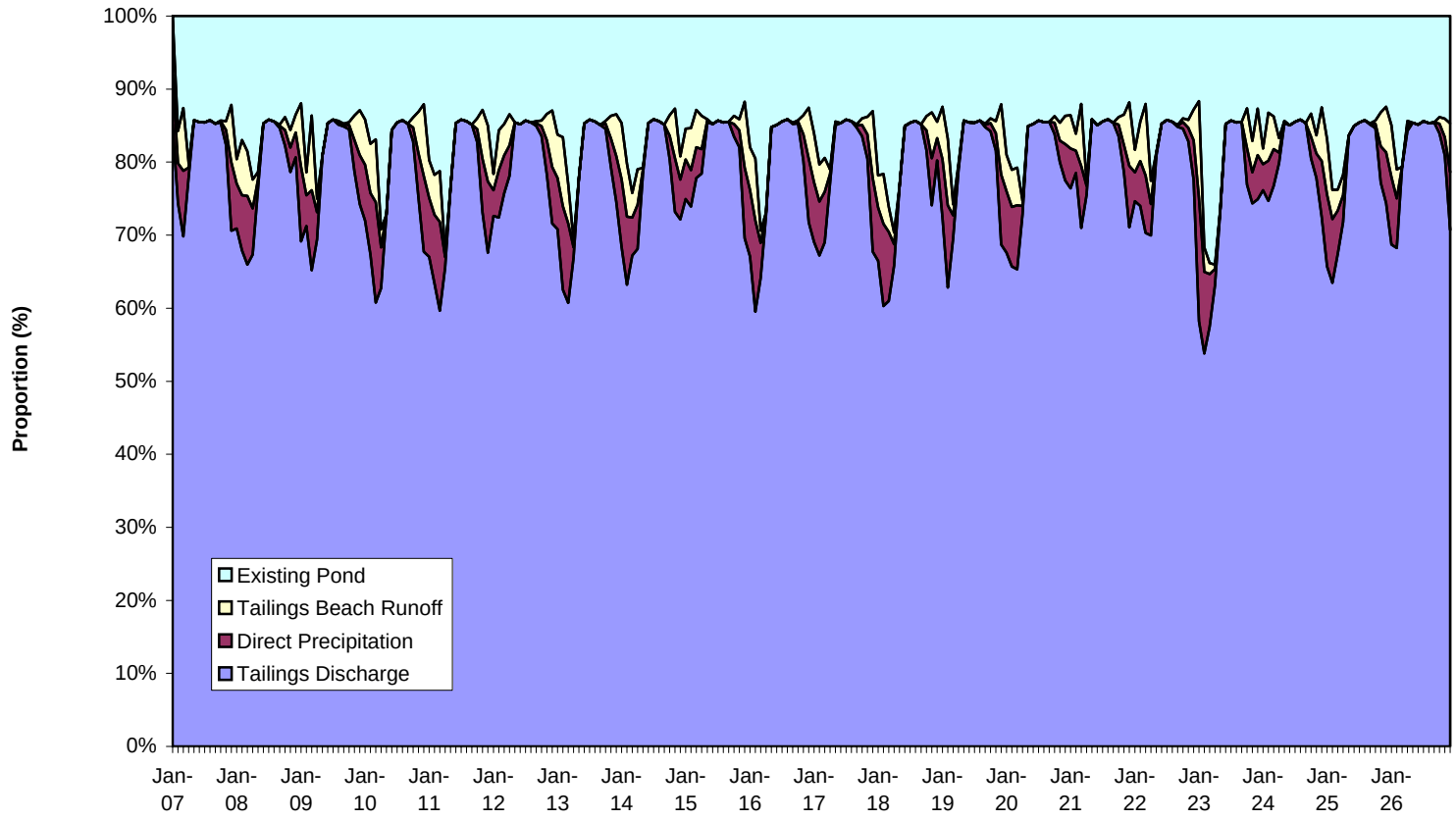
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE	**Literature Sorption Curves**		
DRAWN CR	DATE Mar-07	JOB NO. U04-1334	
CHECKED RV	SCALE na	DWG. NO.	
REVIEWED RV	FILE NO. Tenke - Tailings Model - Runoff (V2).xls	FIGURE NO. **6.5-10**	



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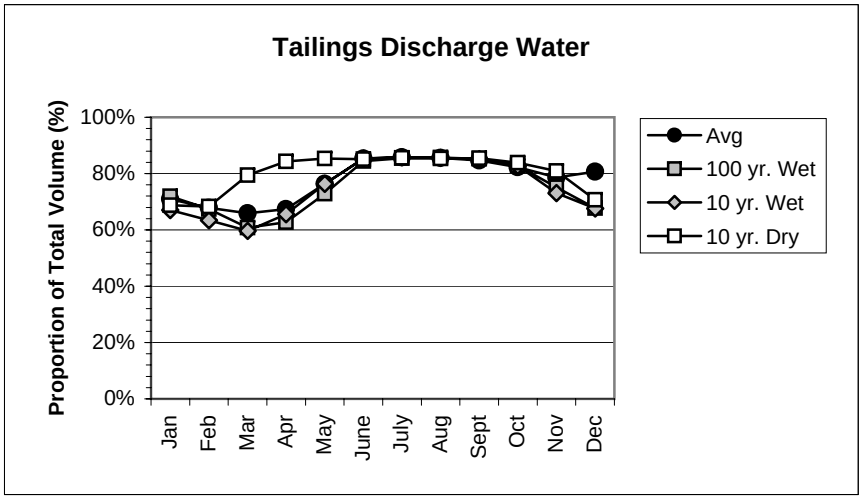
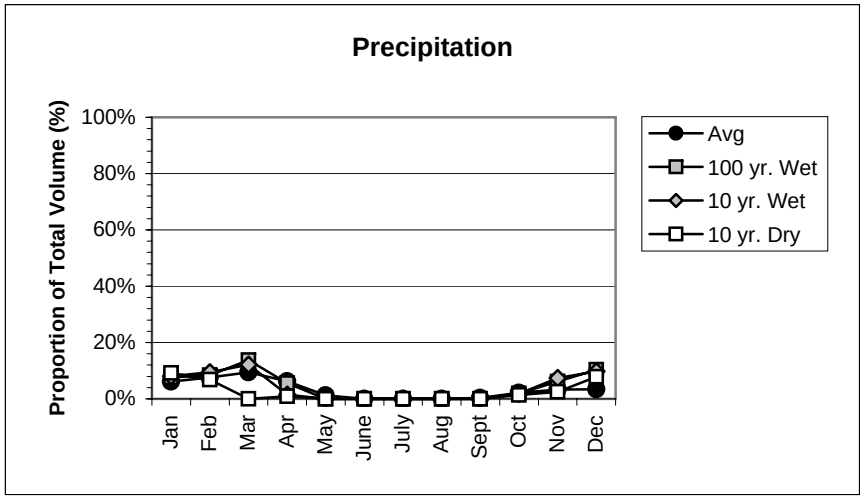
Tenke Fungurume Mining S.A.R.L. (TFM)

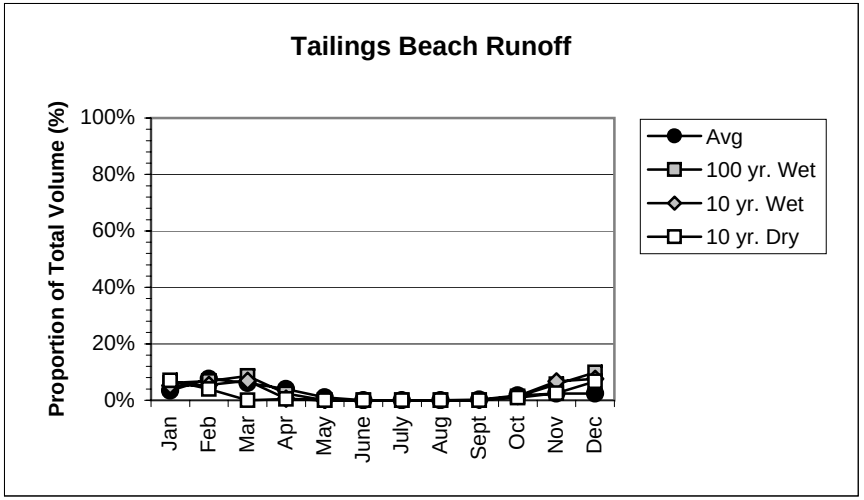
TITLE

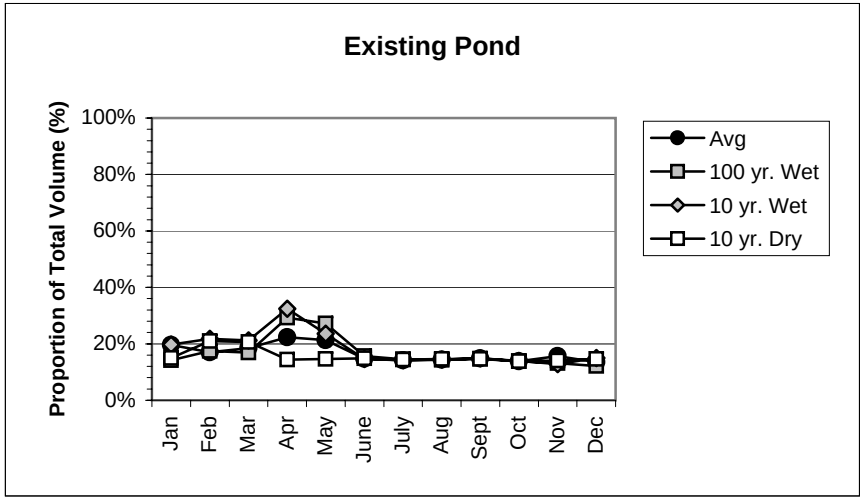
TSF Water Balance - 31 Ha 20 Year Period

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 31Ha (V2).xls	FIGURE NO.	**6.5-11**









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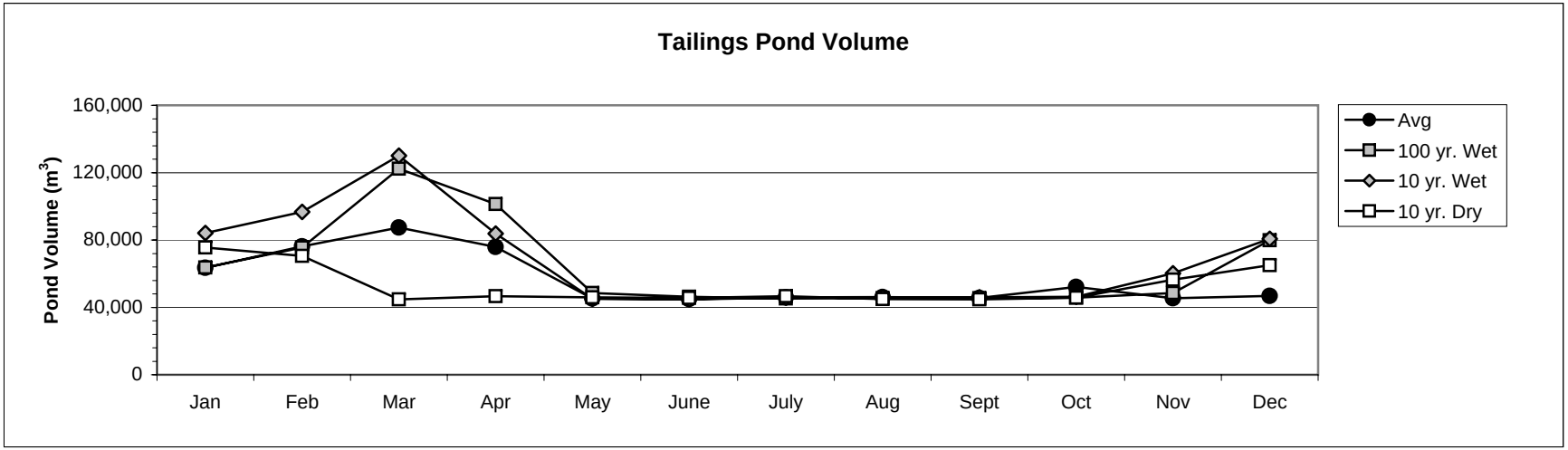
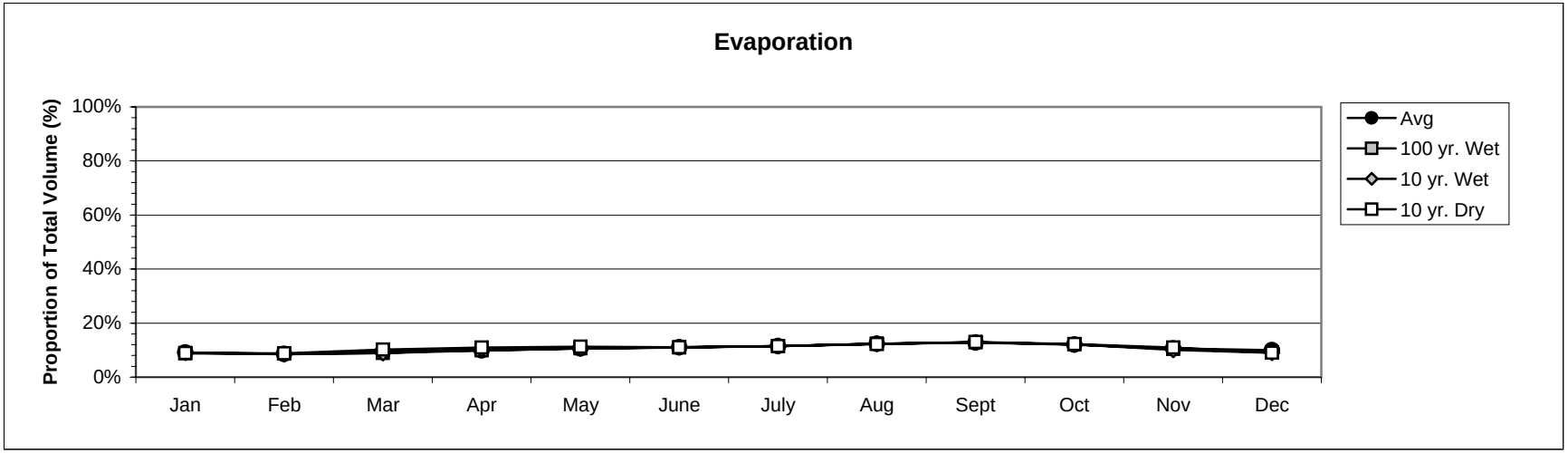
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

31 Hectare TSF Water Balance - Pond Inputs Under Variable Climatic Conditions

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Water Balance (V2).xls	FIGURE NO.	**6.5-12**





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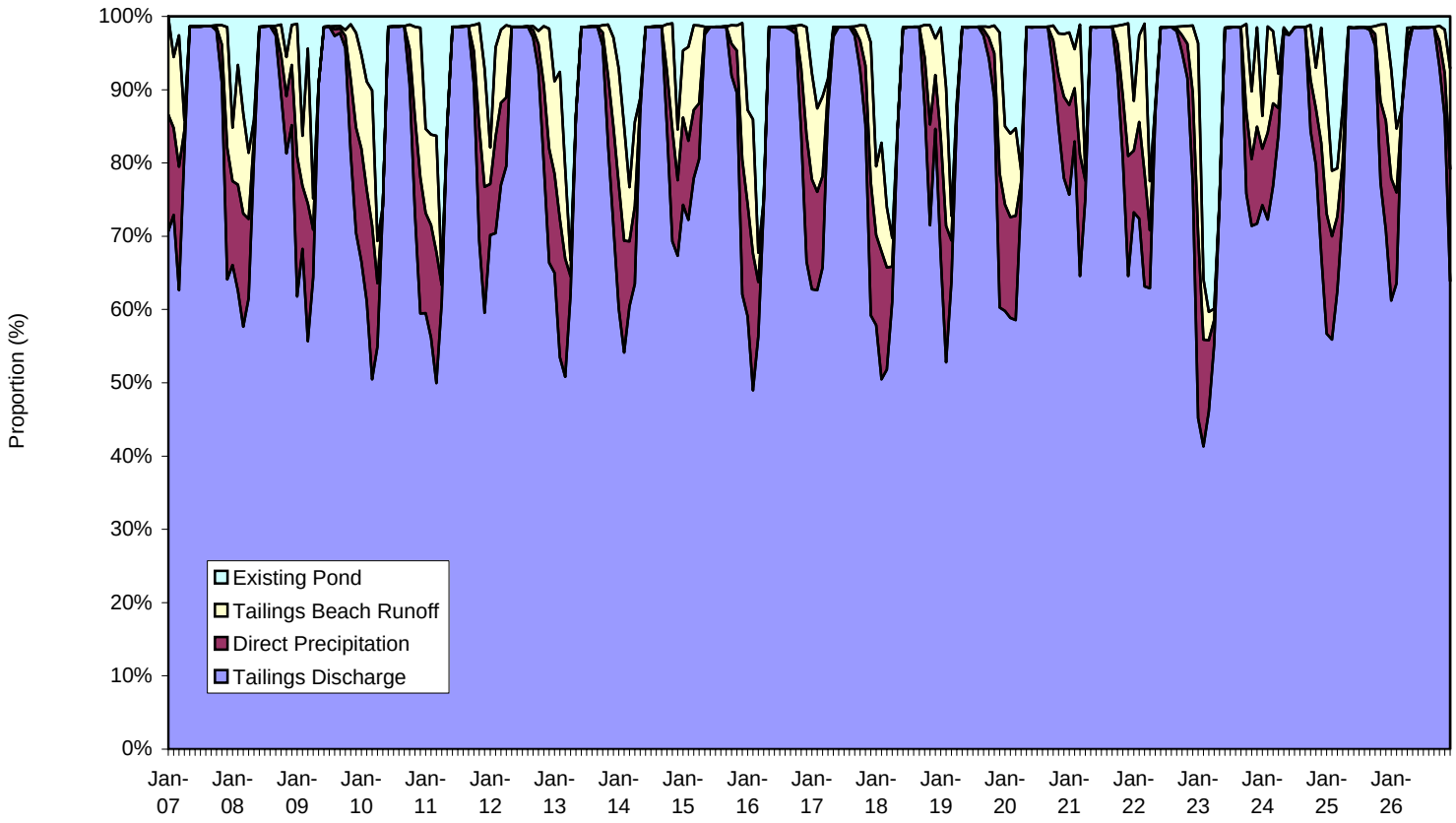
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

31 Hectare TSF Water Balance - Pond Volume and Evaporation

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Water Balance (V2).xls	FIGURE NO.	**6.5-13**



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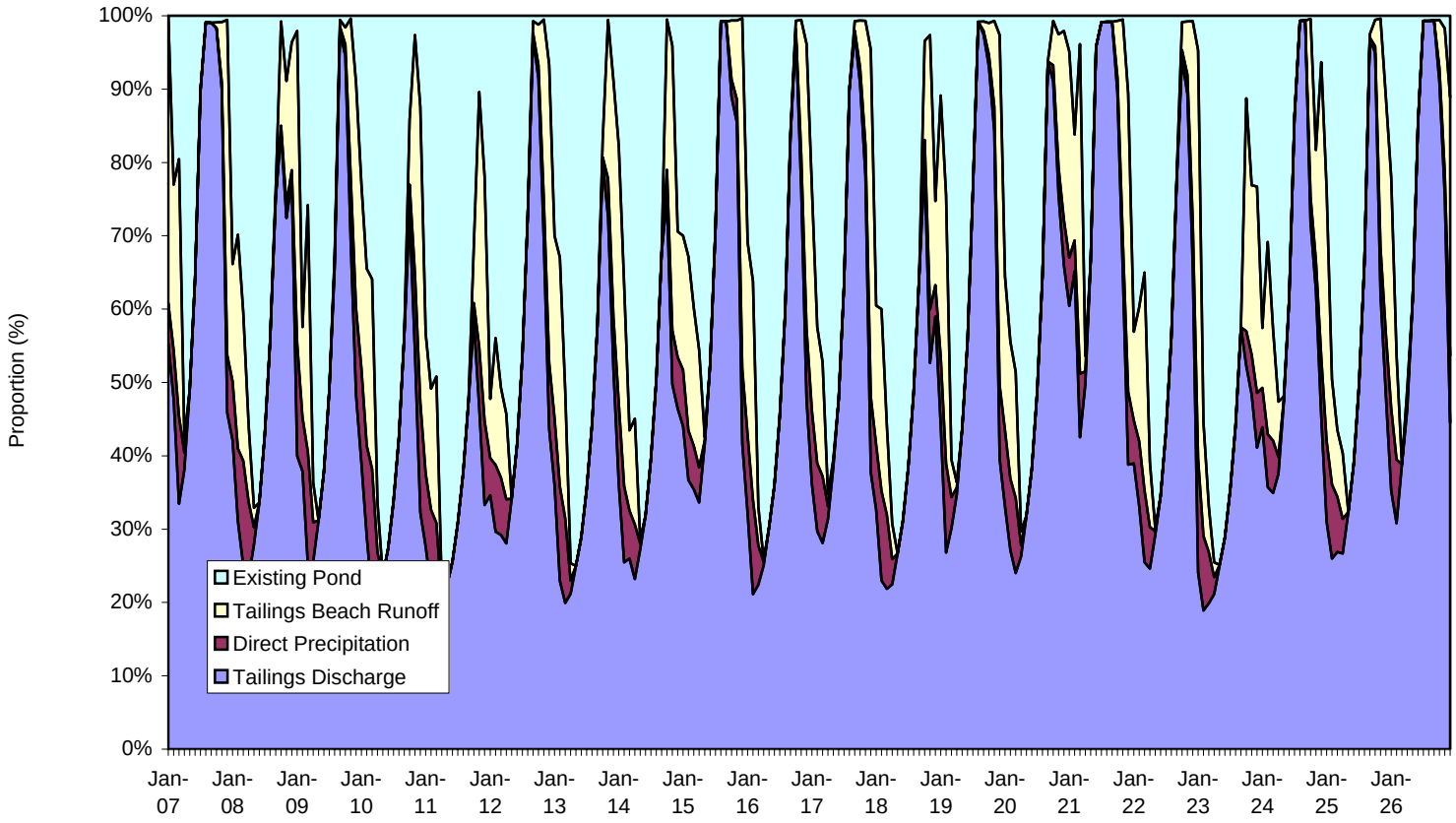
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

TSF Water Balance - 71 Ha 20 Year Period

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 71Ha (V2).xls	FIGURE NO.	**6.5-14**



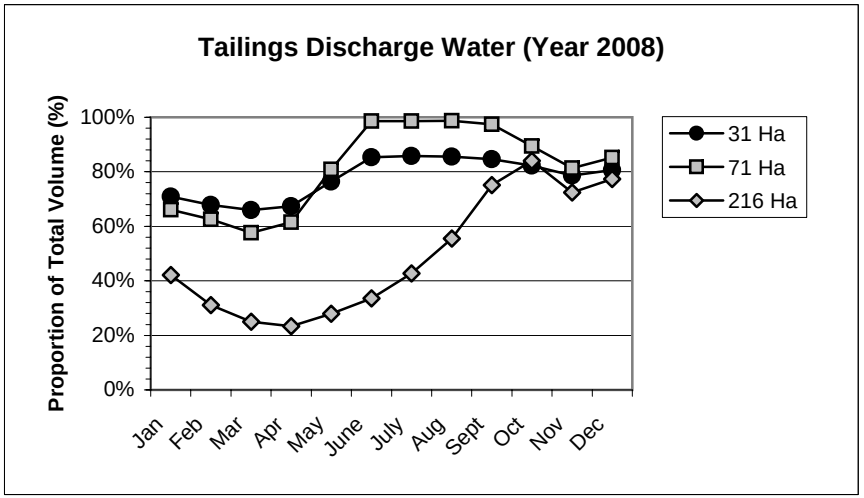
Golder Associates

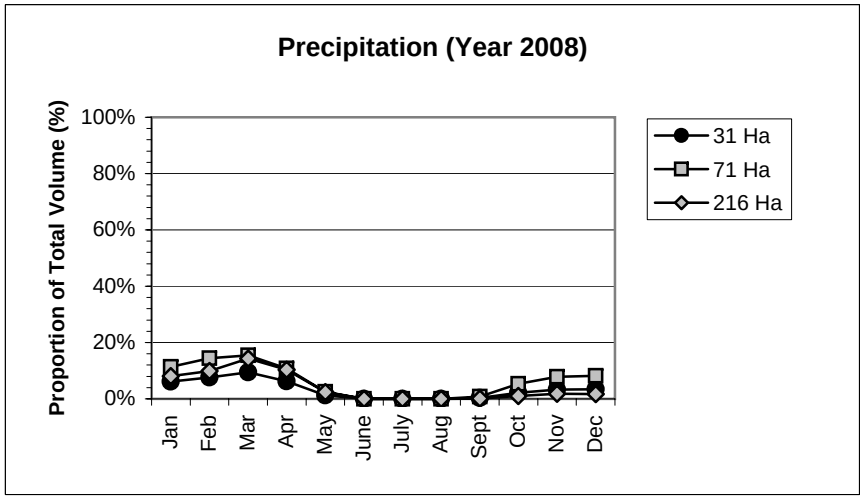
Tenke Fungurume Mining S.A.R.L. (TFM)

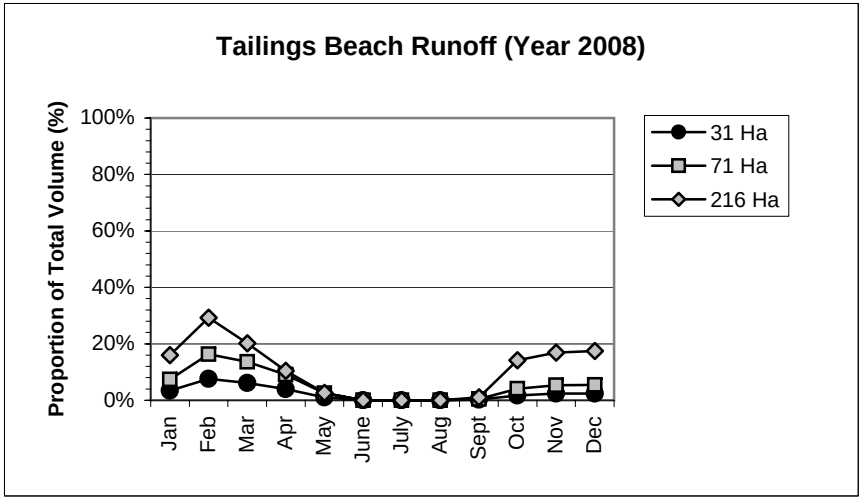
TITLE

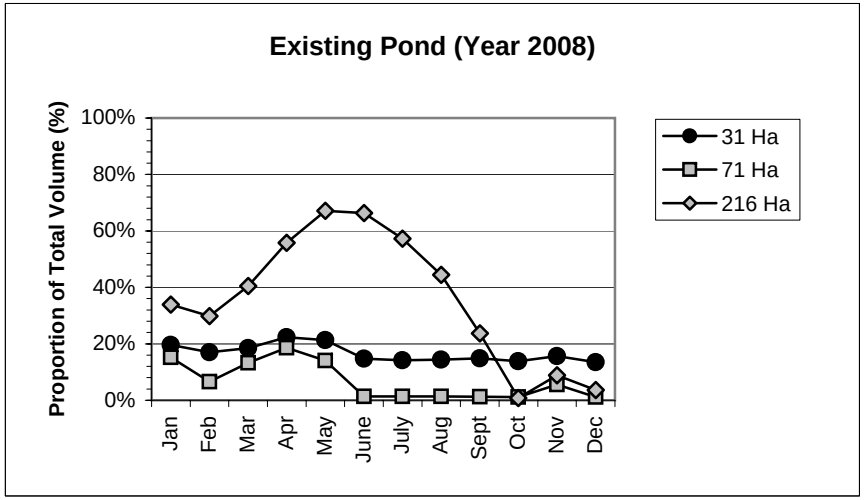
TSF Water Balance - 216 Ha 20 Year Period

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha (V2).xls	FIGURE NO.	**6.5-15**









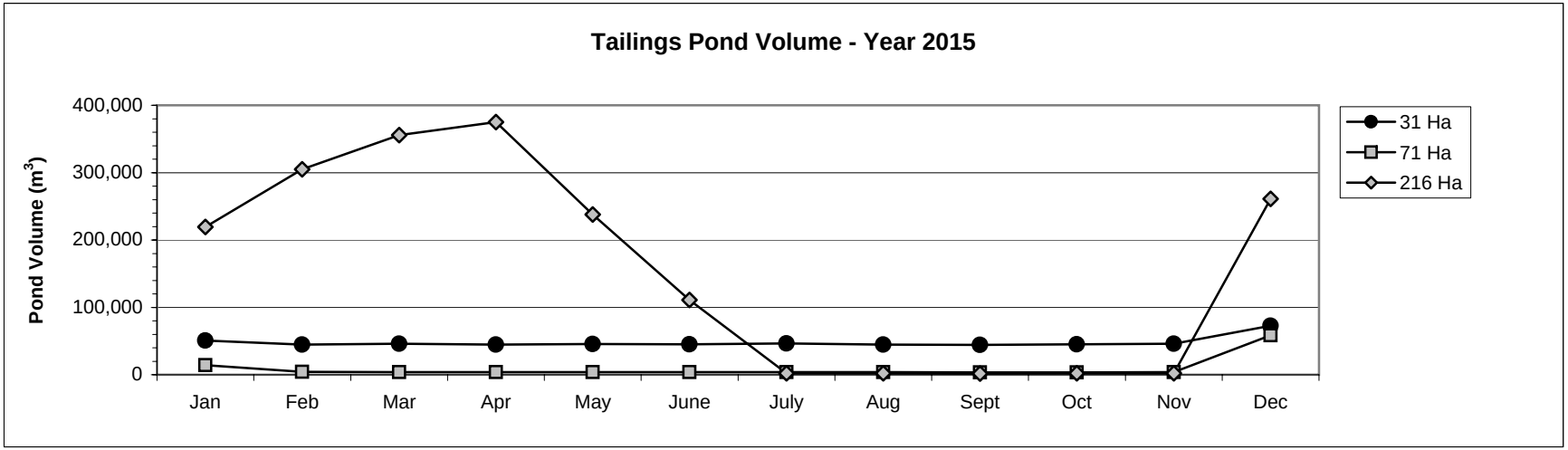
Golder Associates

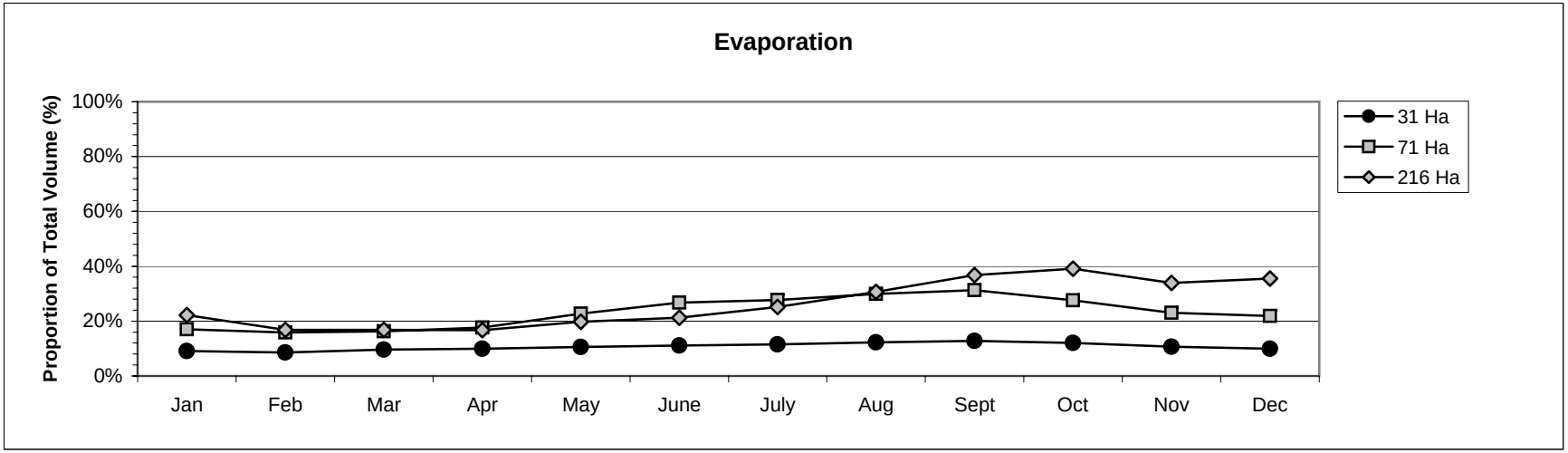
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

TSF Water Balances - Pond Inputs Under Variable Climatic Conditions

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Water Balance (V2).xls	FIGURE NO.	**6.5-16**





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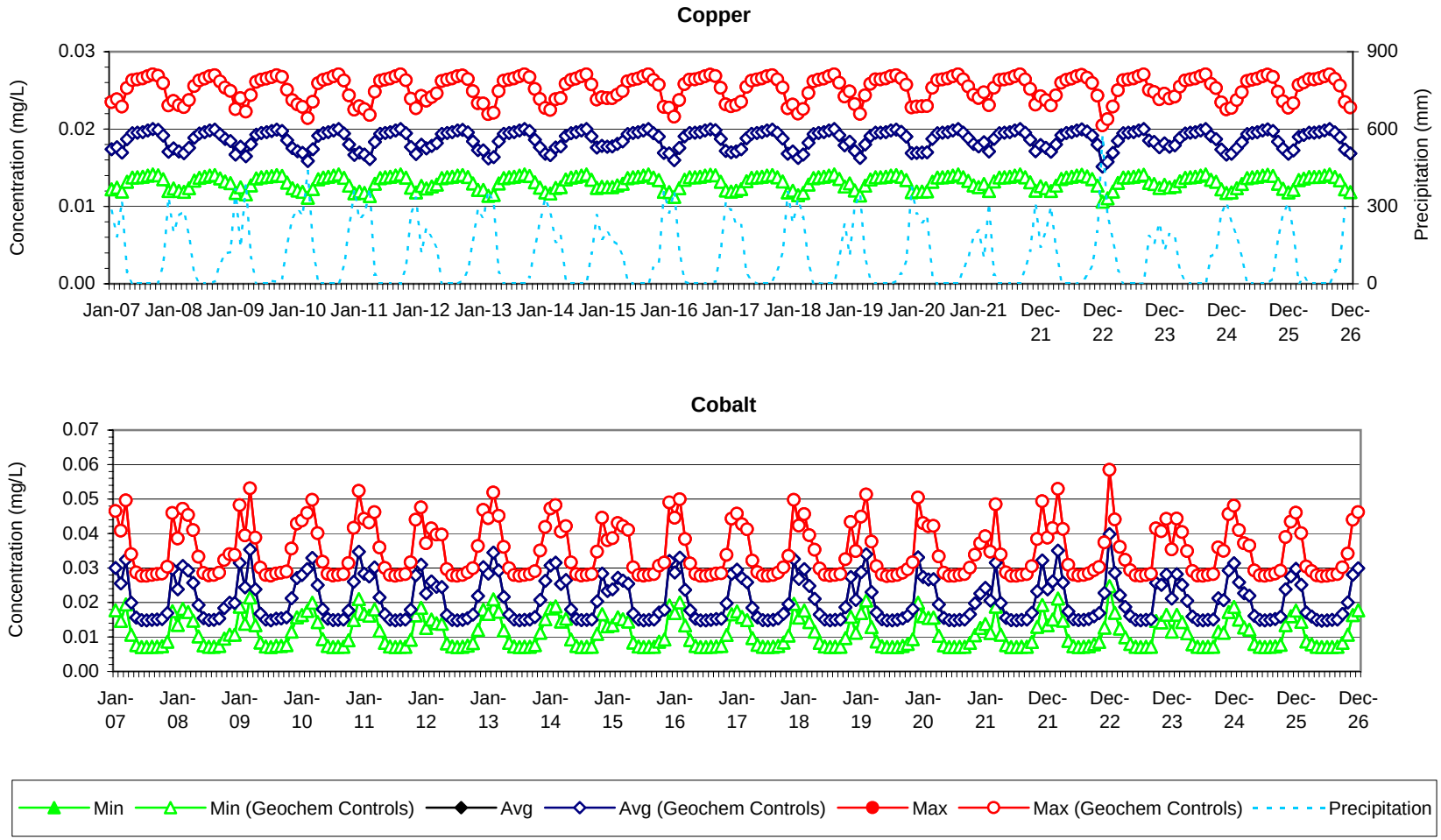
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

TSF Water Balances - Pond Volume and Evaporation

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Water Balance (V2).xls	FIGURE NO.	**6.5-17**



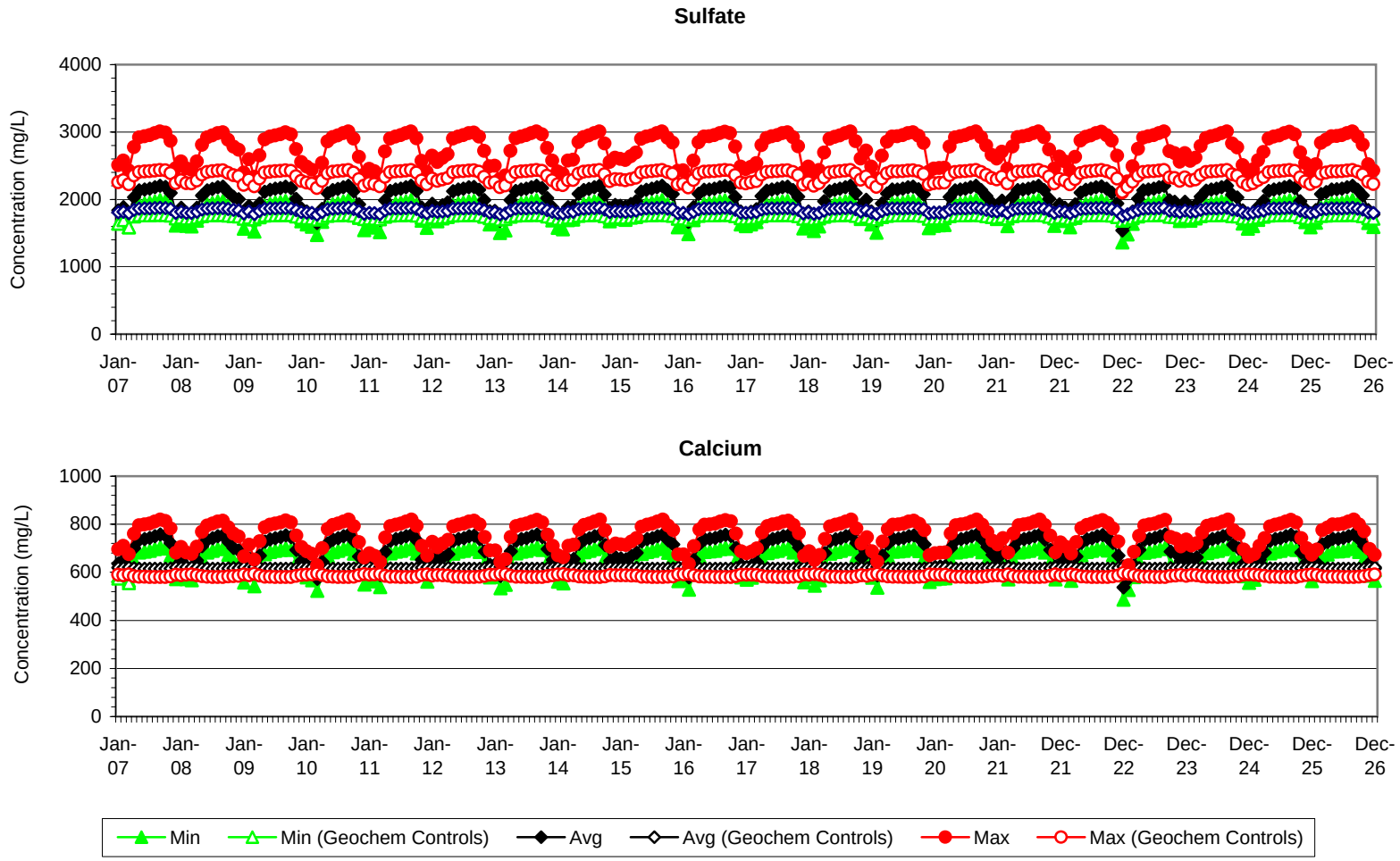
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 31 Ha 20 Year Simulation Copper and Cobalt Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 31Ha (V2).xls	FIGURE NO.	6.5-18



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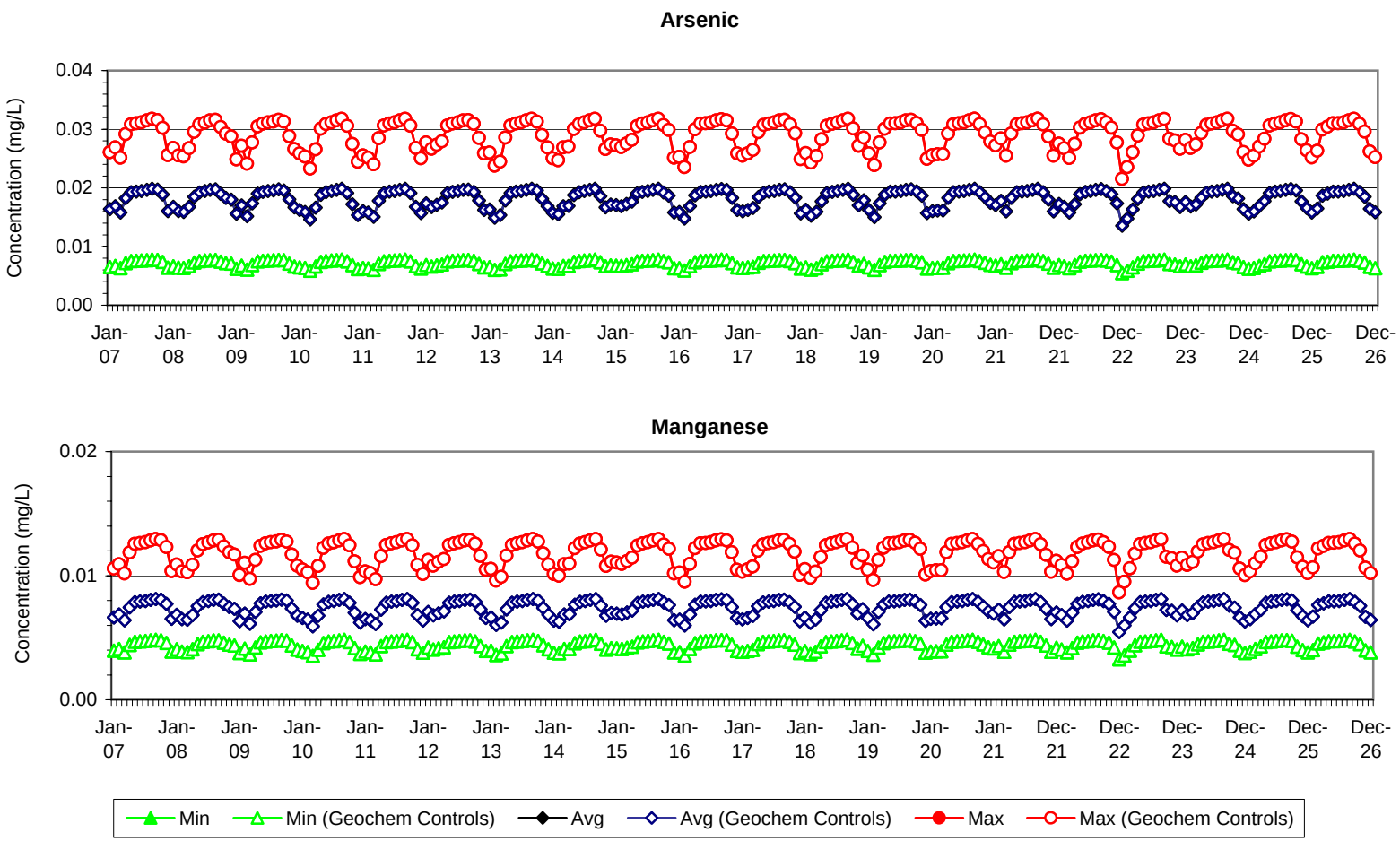
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 31 Ha 20 Year Simulation Sulfate and Calcium Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 31Ha (V2).xls	FIGURE NO.	6.5-19



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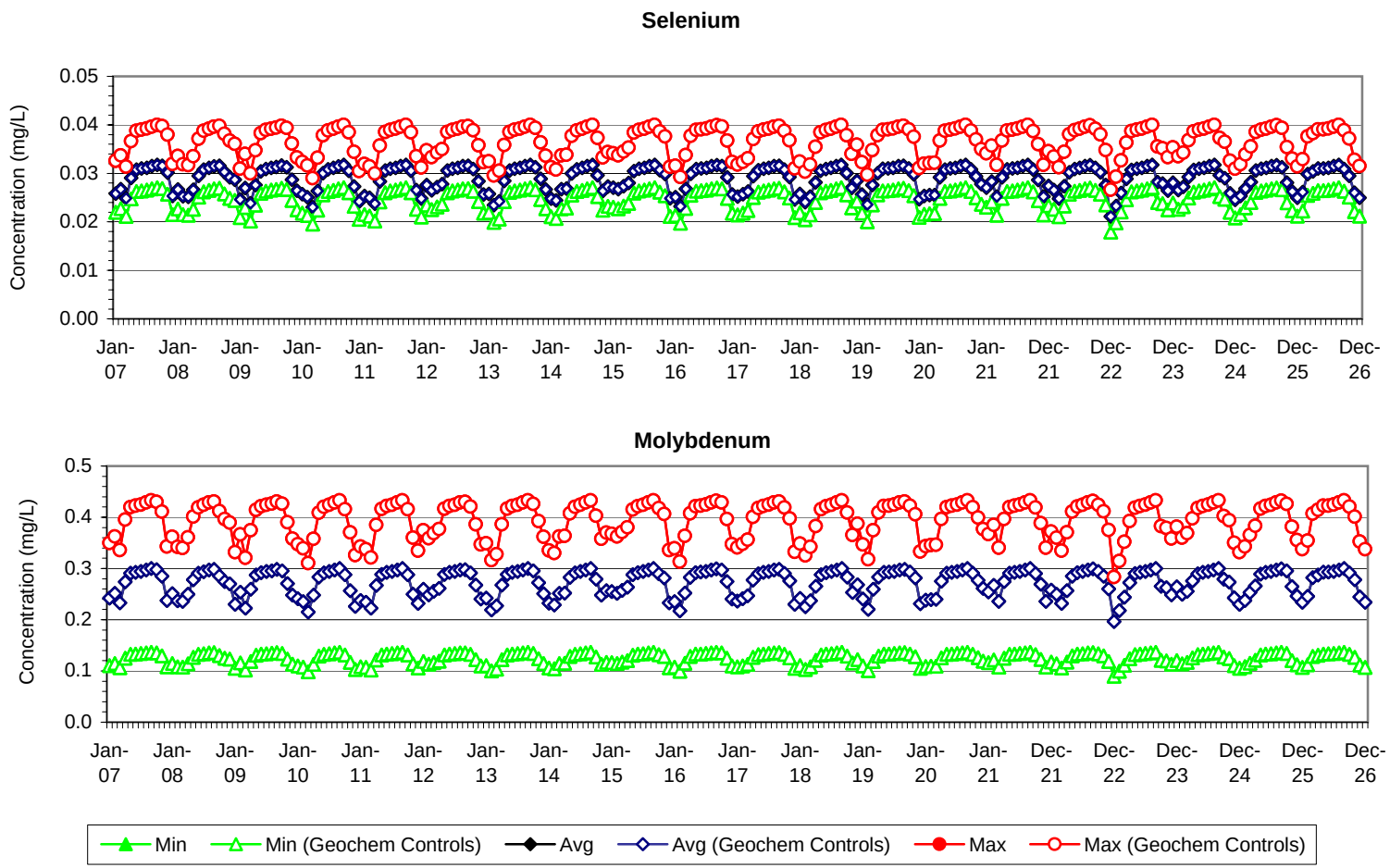
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 31 Ha 20 Year Simulation Arsenic and Manganese Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 31Ha (V2).xls	FIGURE NO.	**6.5-20**



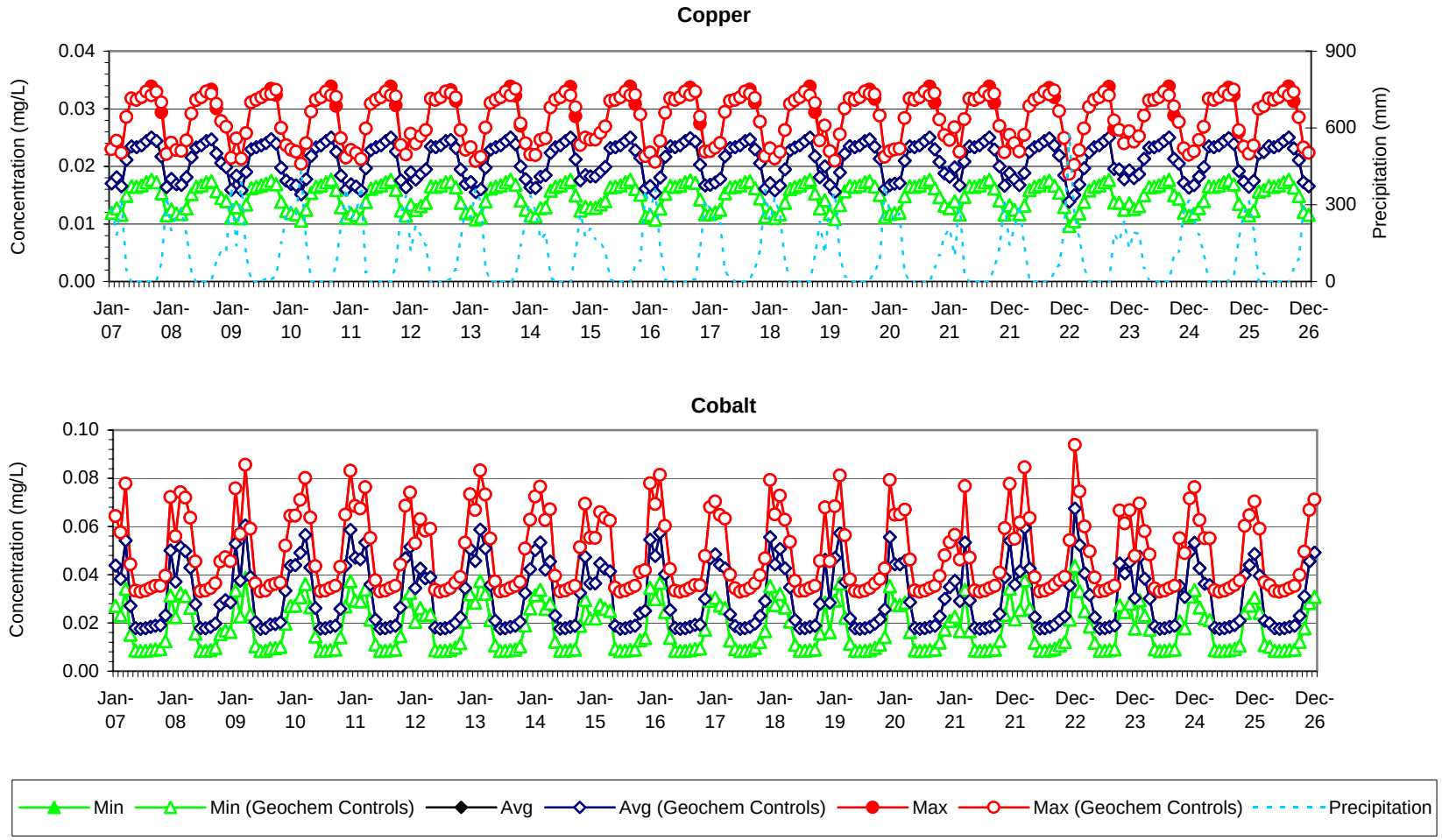
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 31 Ha 20 Year Simulation Selenium and Molybdenum Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 31Ha (V2).xls	FIGURE NO.	6.5-21



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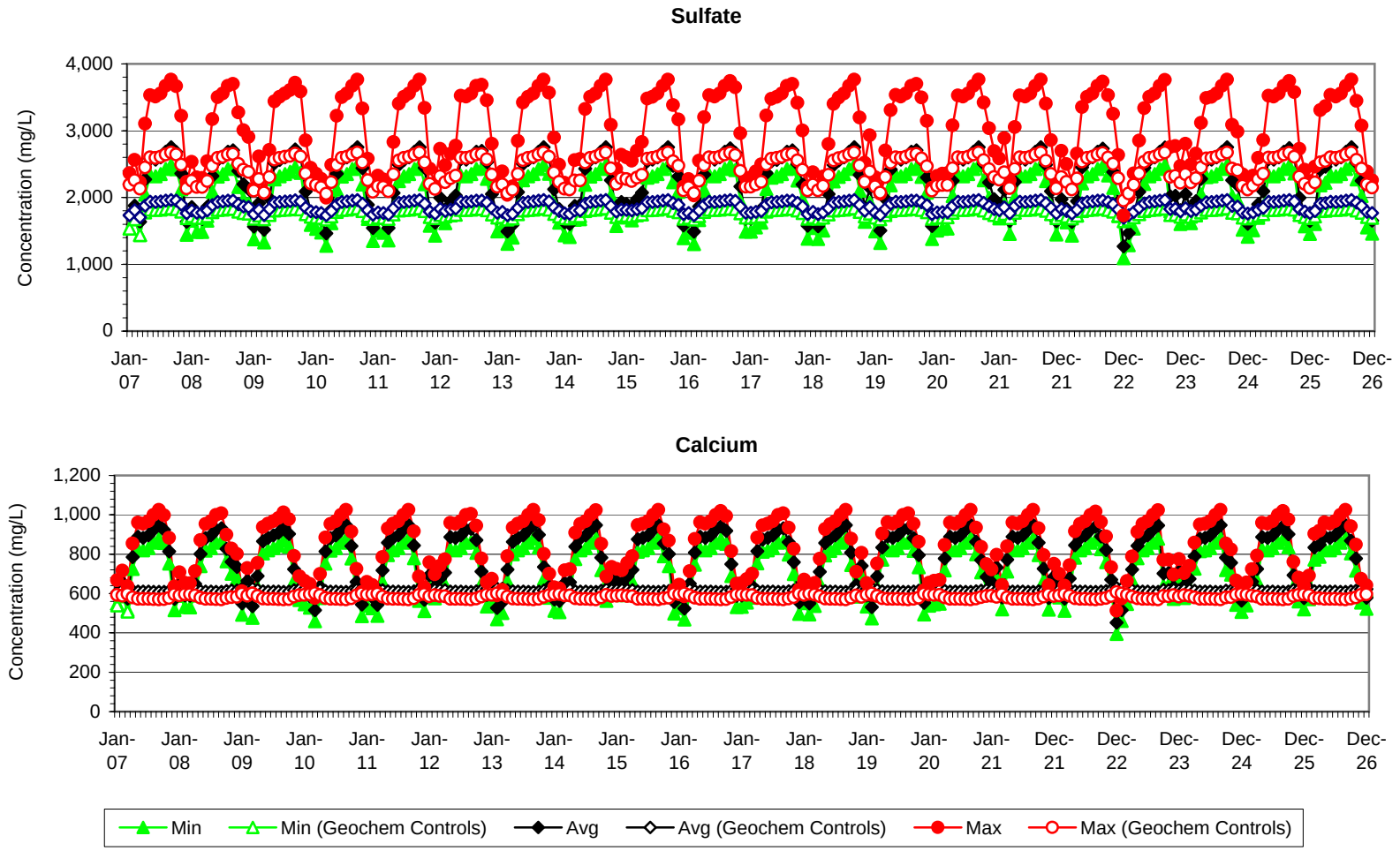
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 71 Ha 20 Year Simulation Copper and Cobalt Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 71Ha (V2).xls	FIGURE NO.	6.5-22



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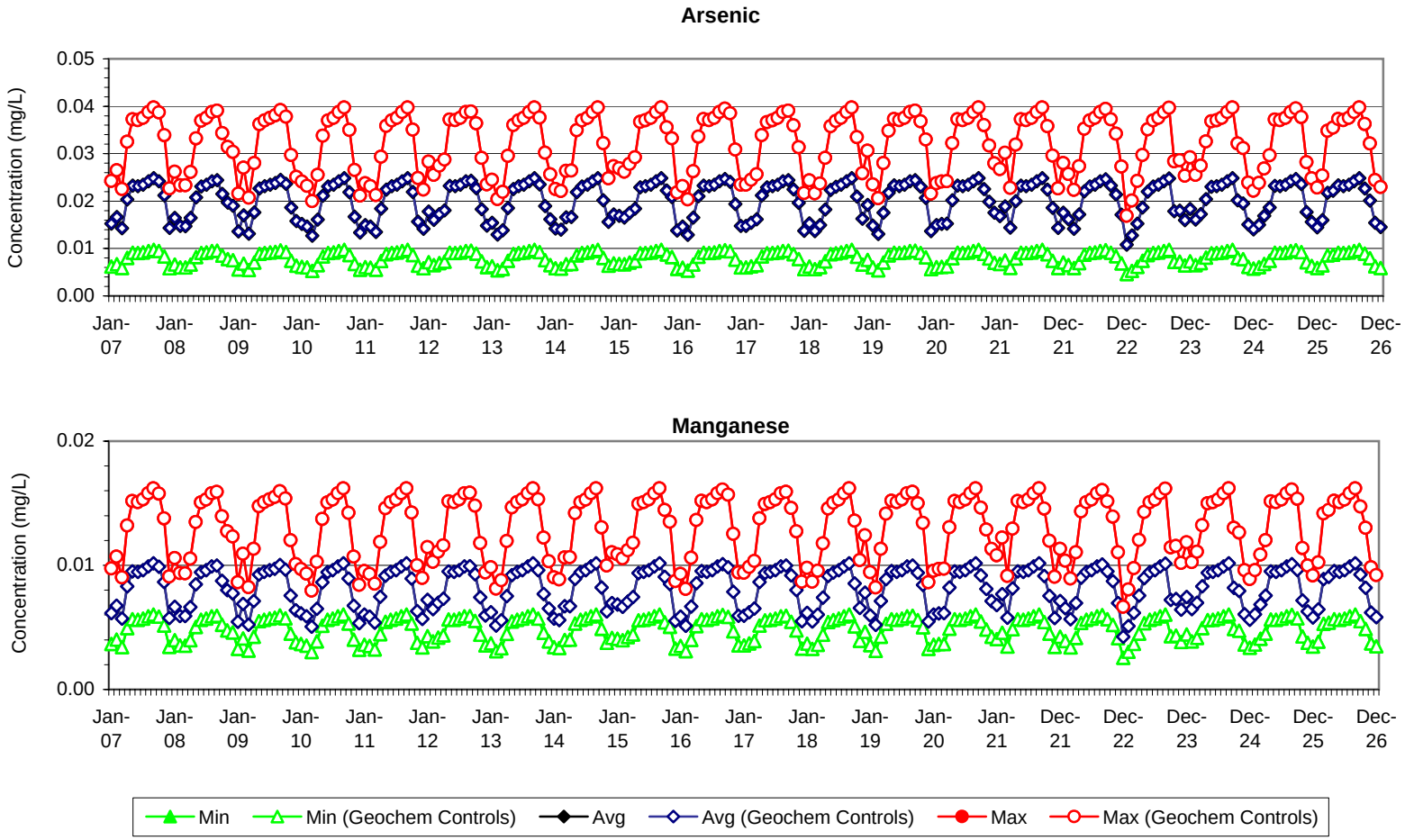
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 71 Ha 20 Year Simulation Sulfate and Calcium Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 71Ha (V2).xls	FIGURE NO.	6.5-23



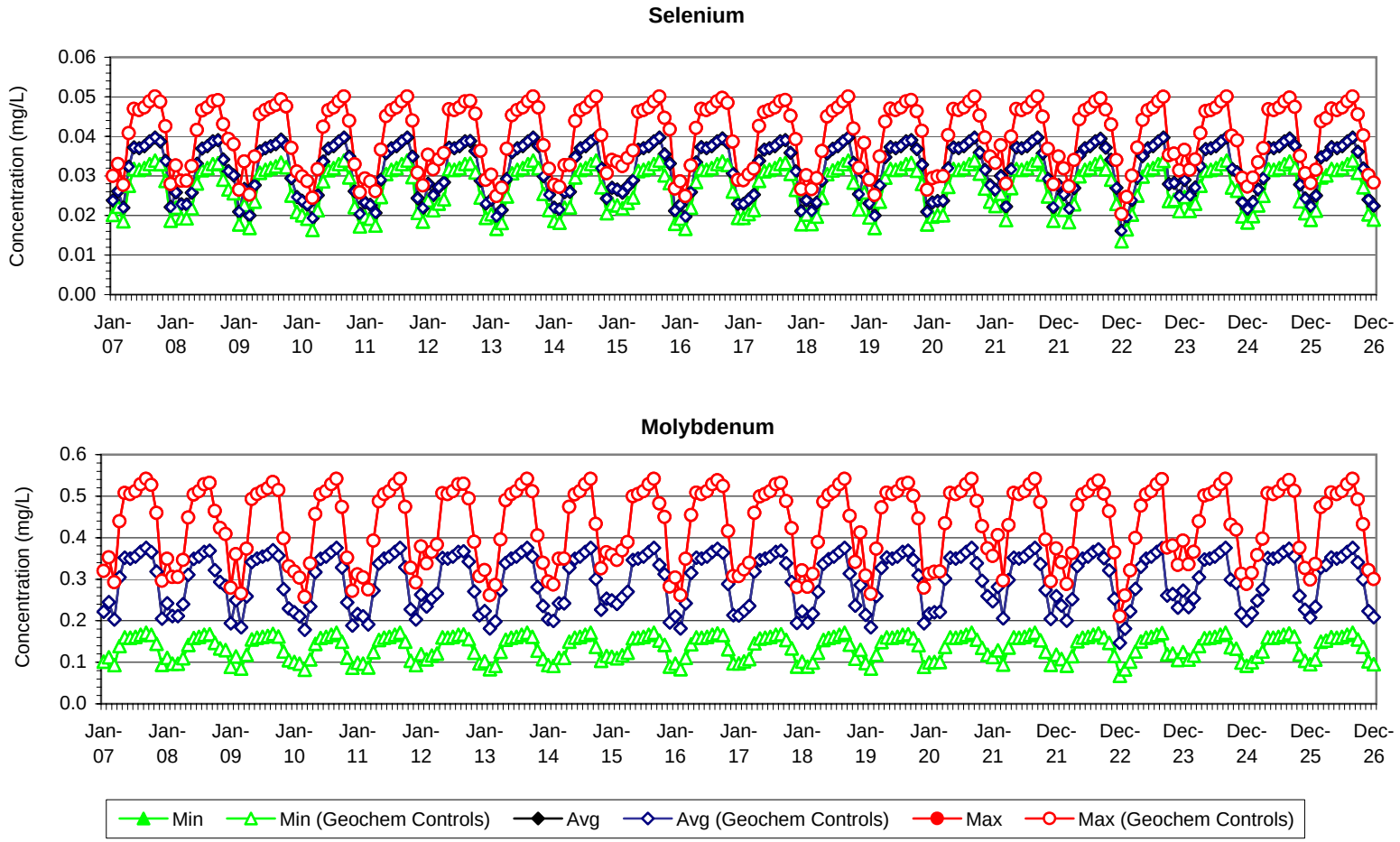
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 71 Ha 20 Year Simulation Arsenic and Manganese Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 71Ha (V2).xls	FIGURE NO.	6.5-24



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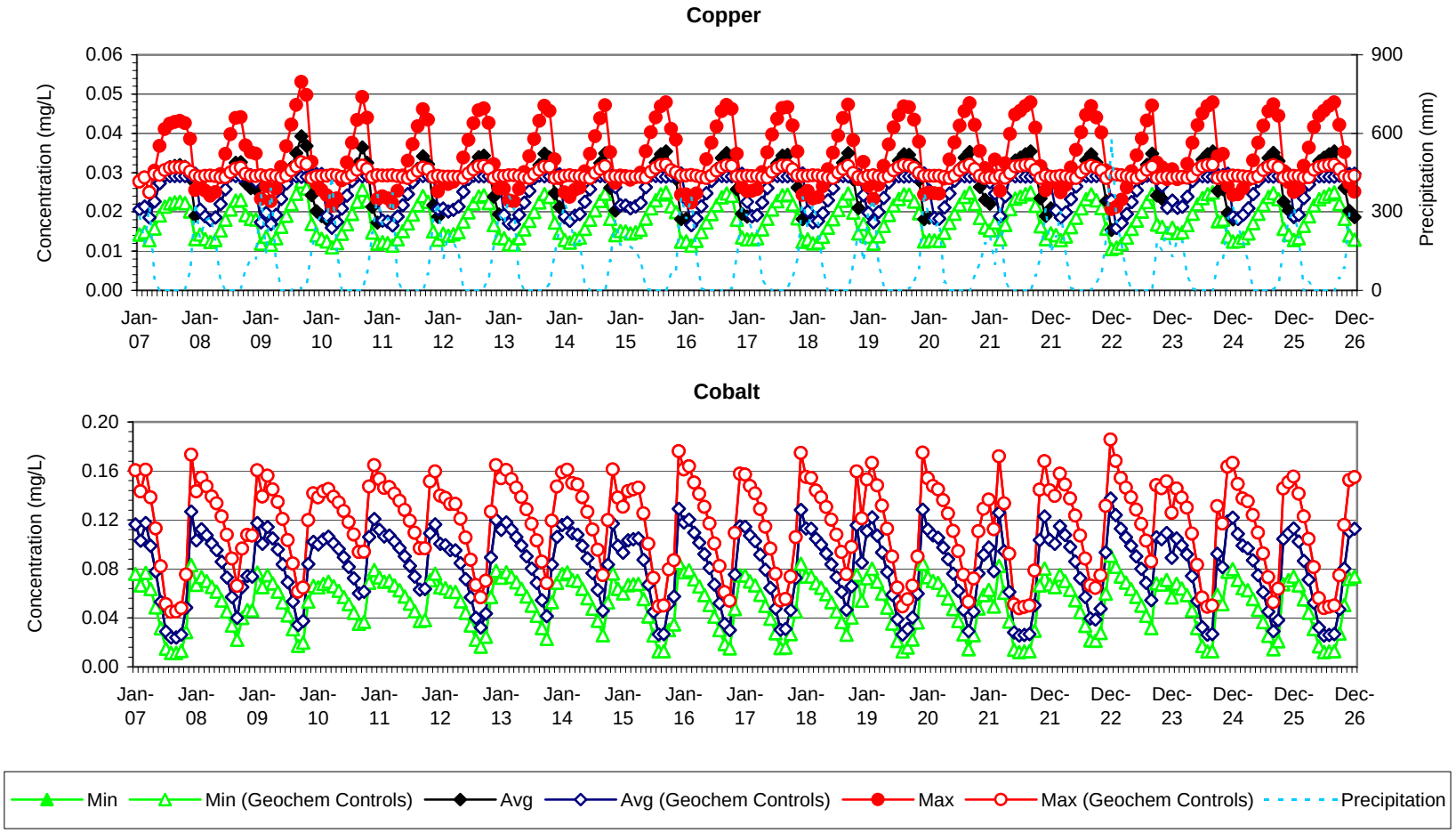
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 71 Ha 20 Year Simulation Selenium and Molybdenum Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 71Ha (V2).xls	FIGURE NO.	6.5-25



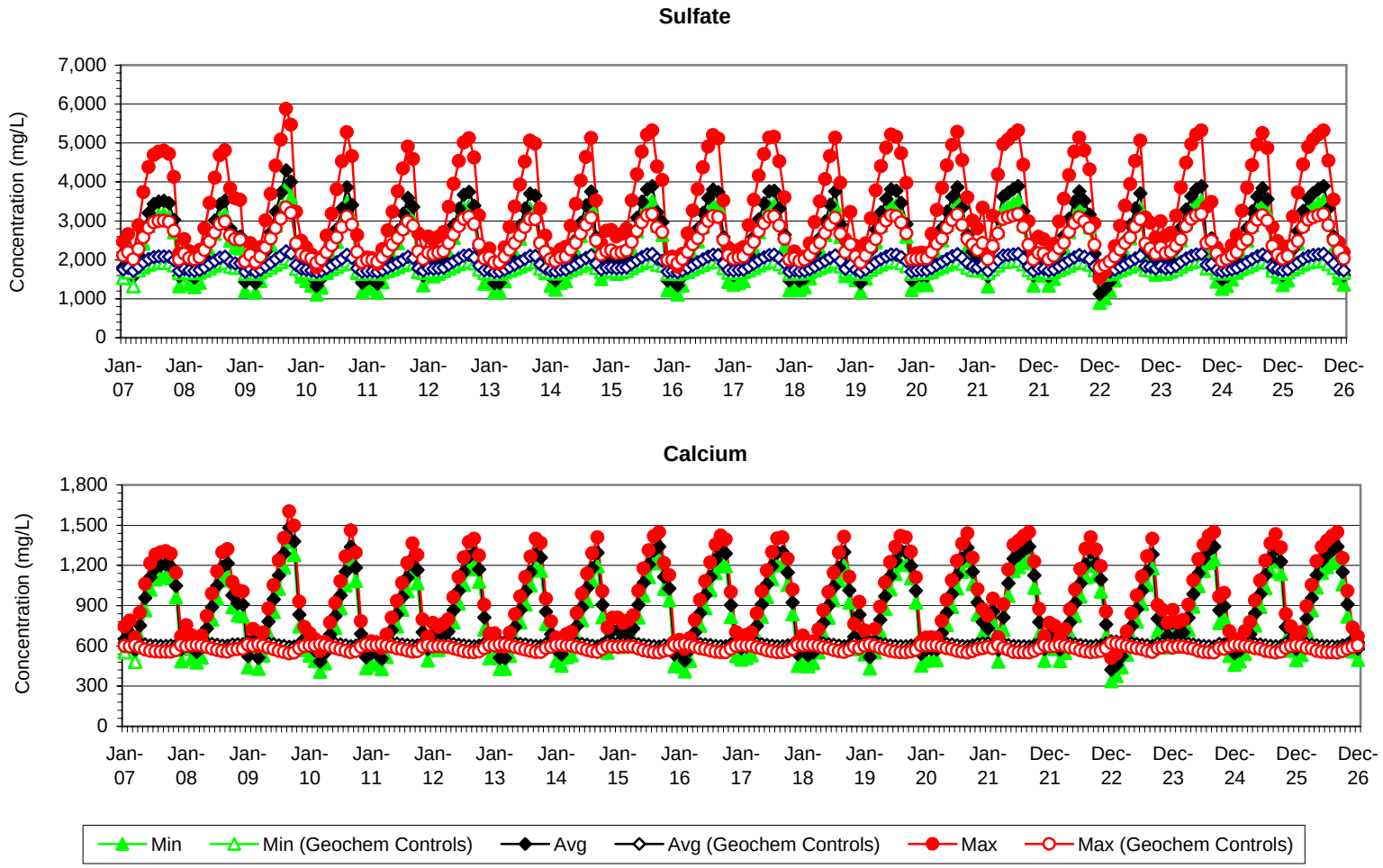
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 216 Ha 20 Year Simulation Copper and Cobalt Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha (V2).xls	FIGURE NO.	6.5-26



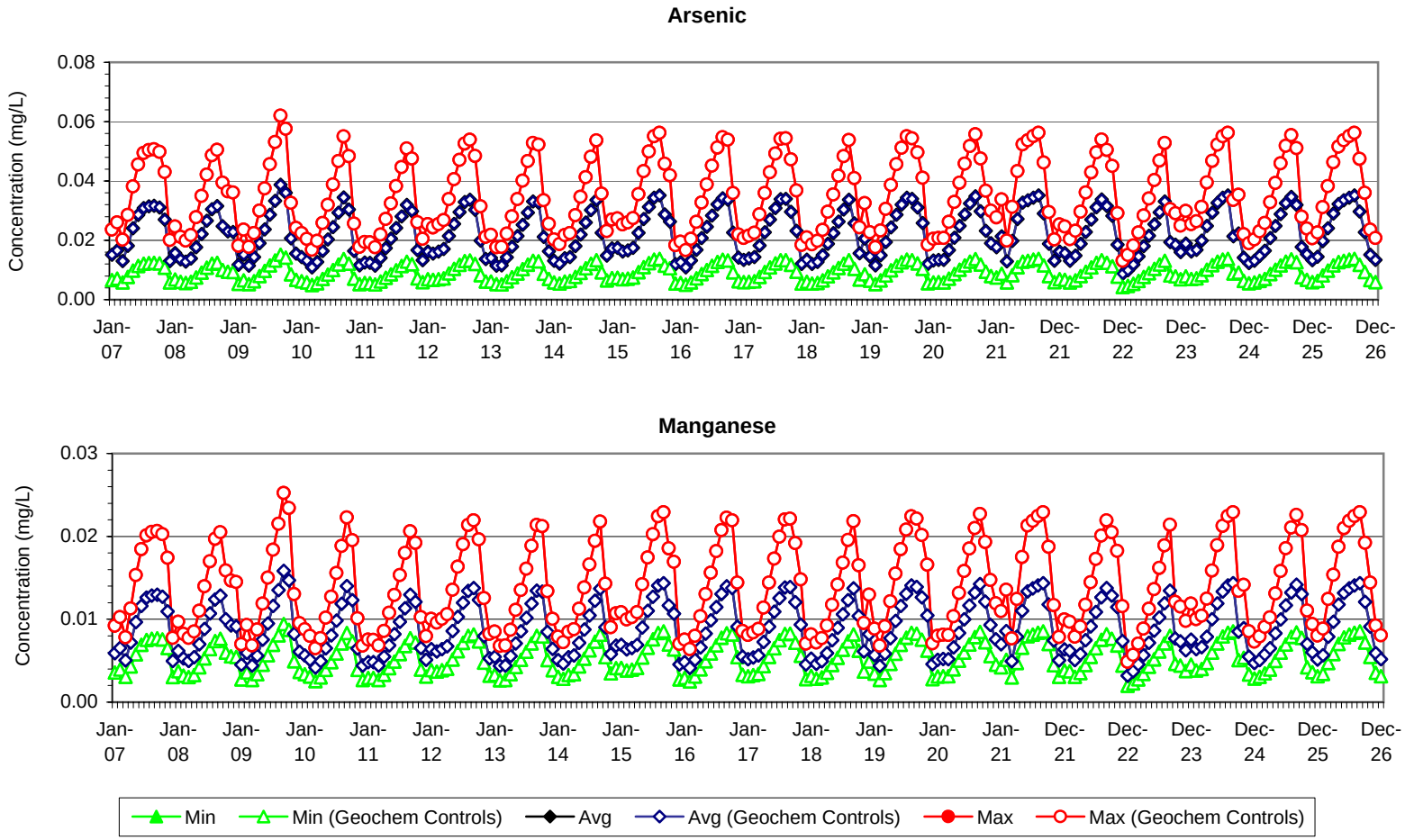
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 216 Ha 20 Year Simulation Sulfate and Calcium Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha (V2).xls	FIGURE NO.	6.5-27



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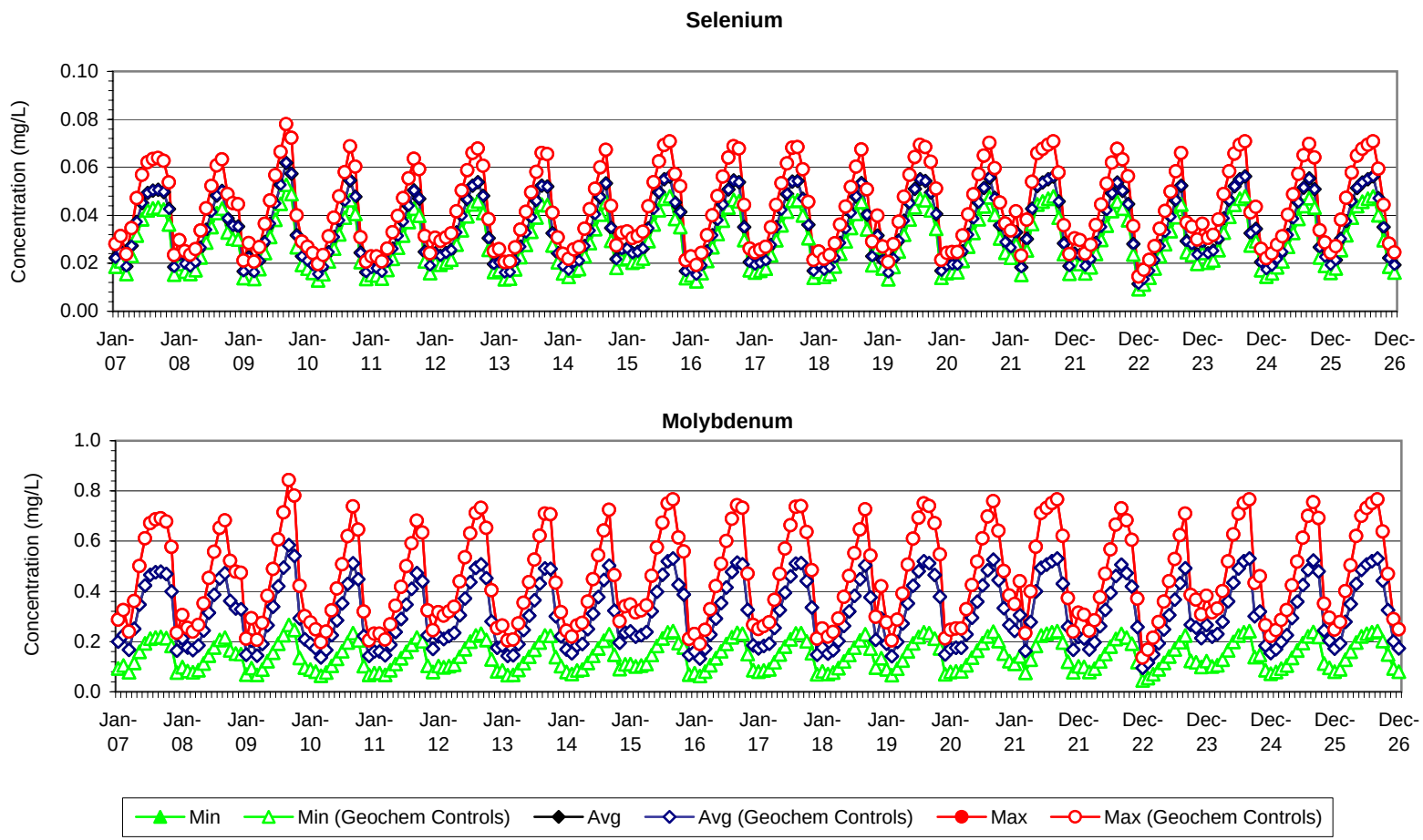
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 216 Ha 20 Year Simulation Arsenic and Manganese Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha (V2).xls	FIGURE NO.	6.5-28



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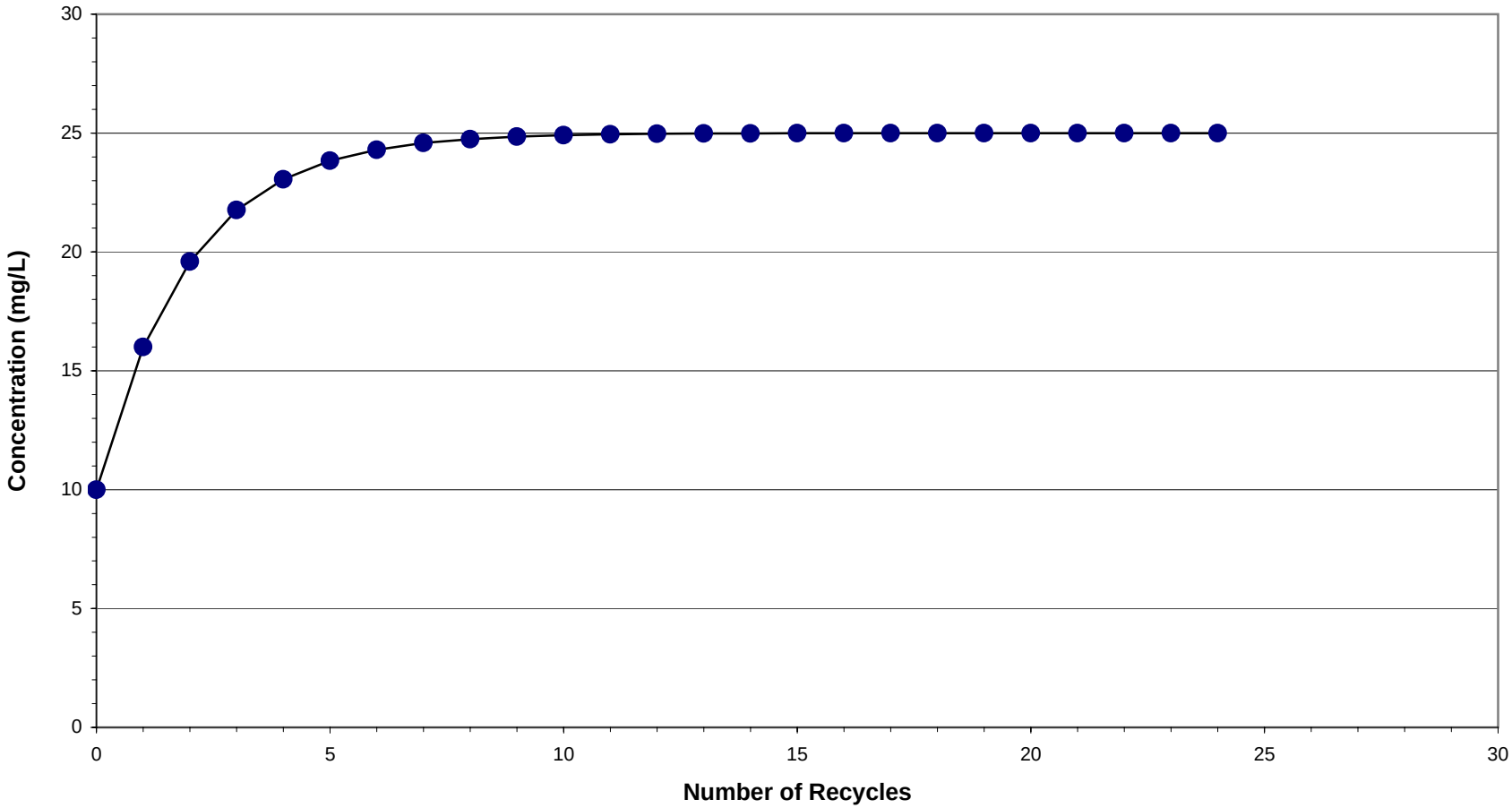
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 216 Ha 20 Year Simulation Selenium and Molybdenum Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha (V2).xls	FIGURE NO.	6.5-29



Note: Assumes 60% of TSF pond water is recycled.

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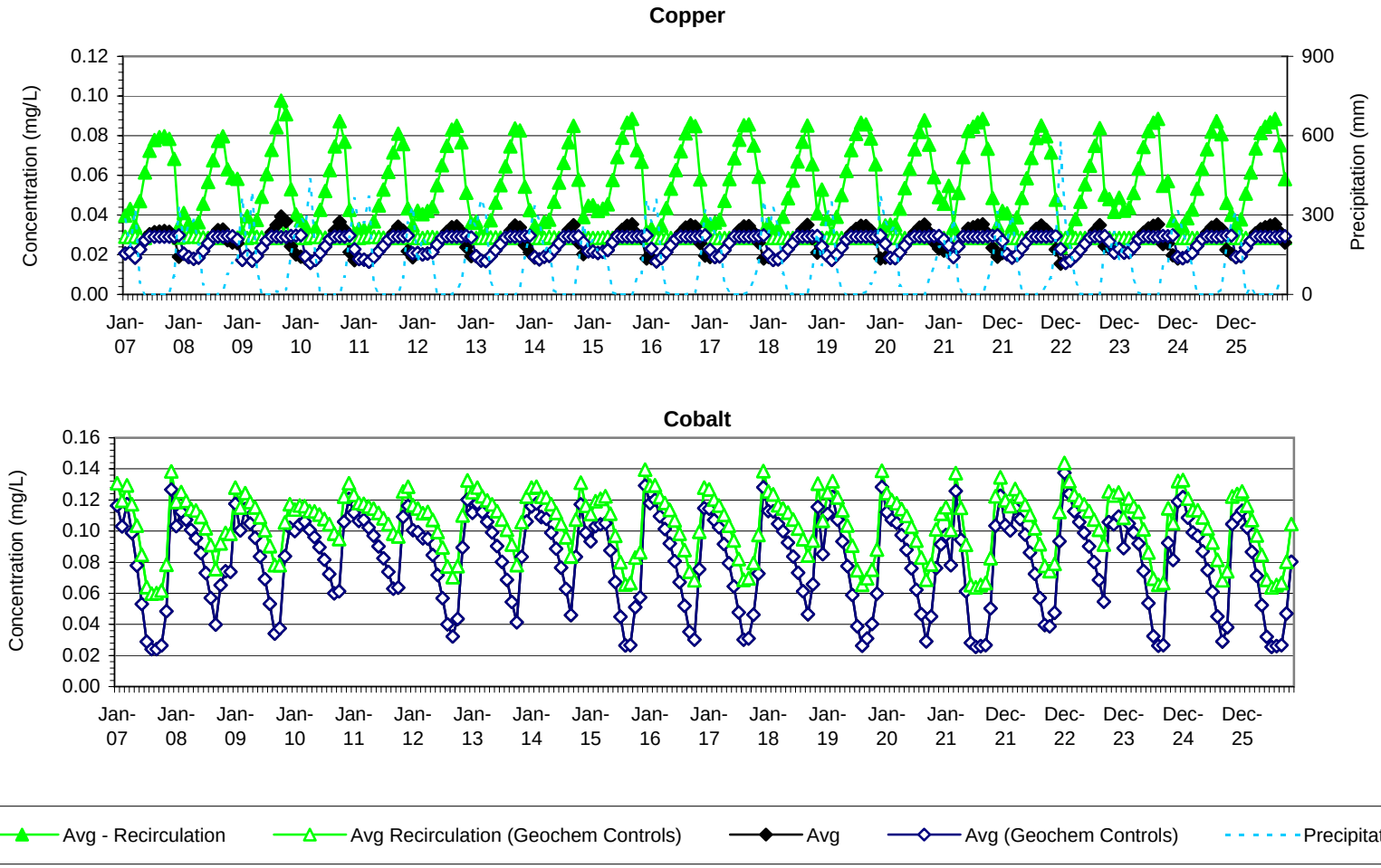
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Effect of Recirculation on Tailings Discharge

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - Recirc (V2).xls	FIGURE NO.	**6.5-30**



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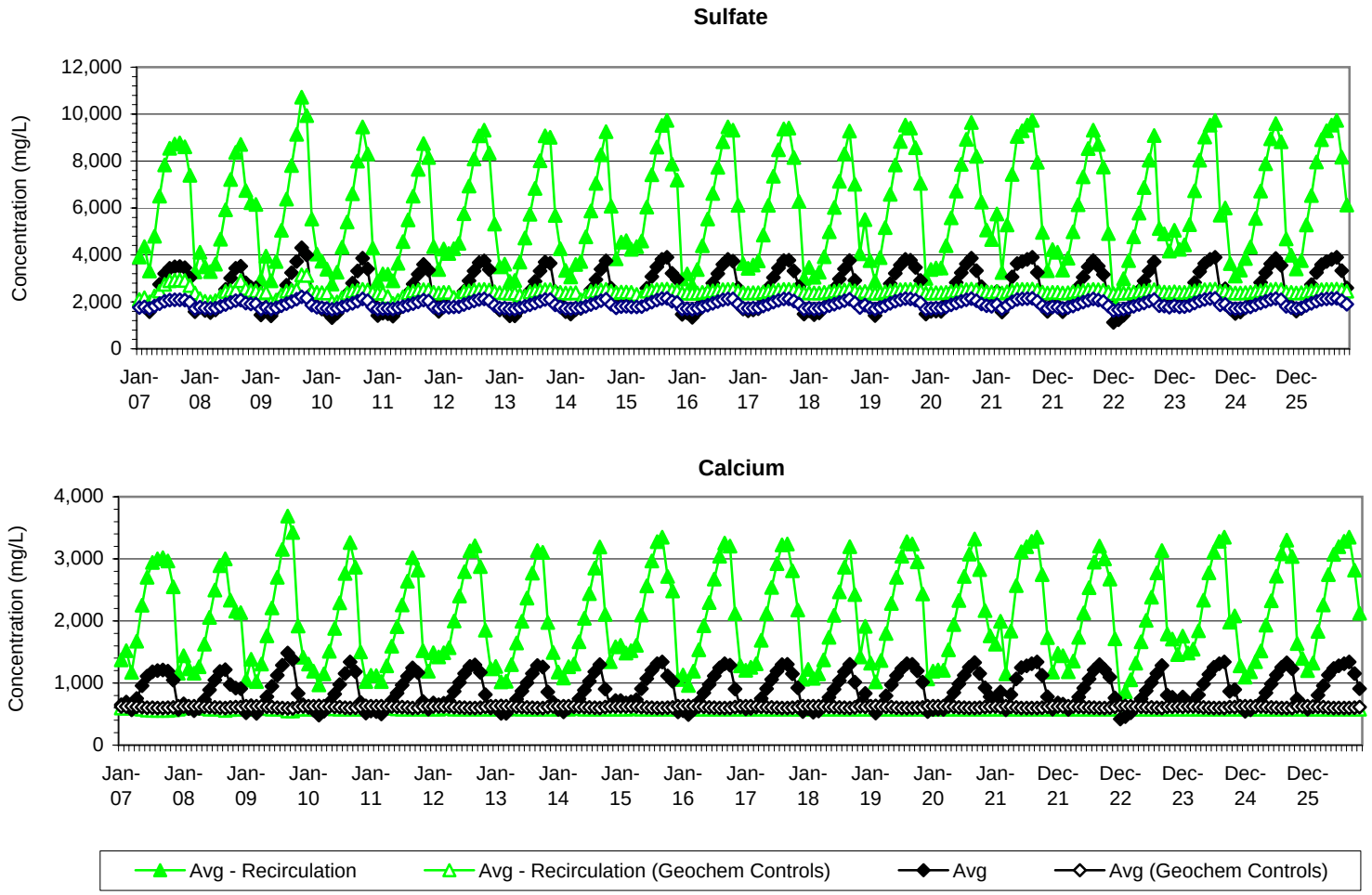
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 216 Ha Recirculation Simulation Copper and Cobalt Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha Recirc (V2).xls	FIGURE NO.	**6.5-31**



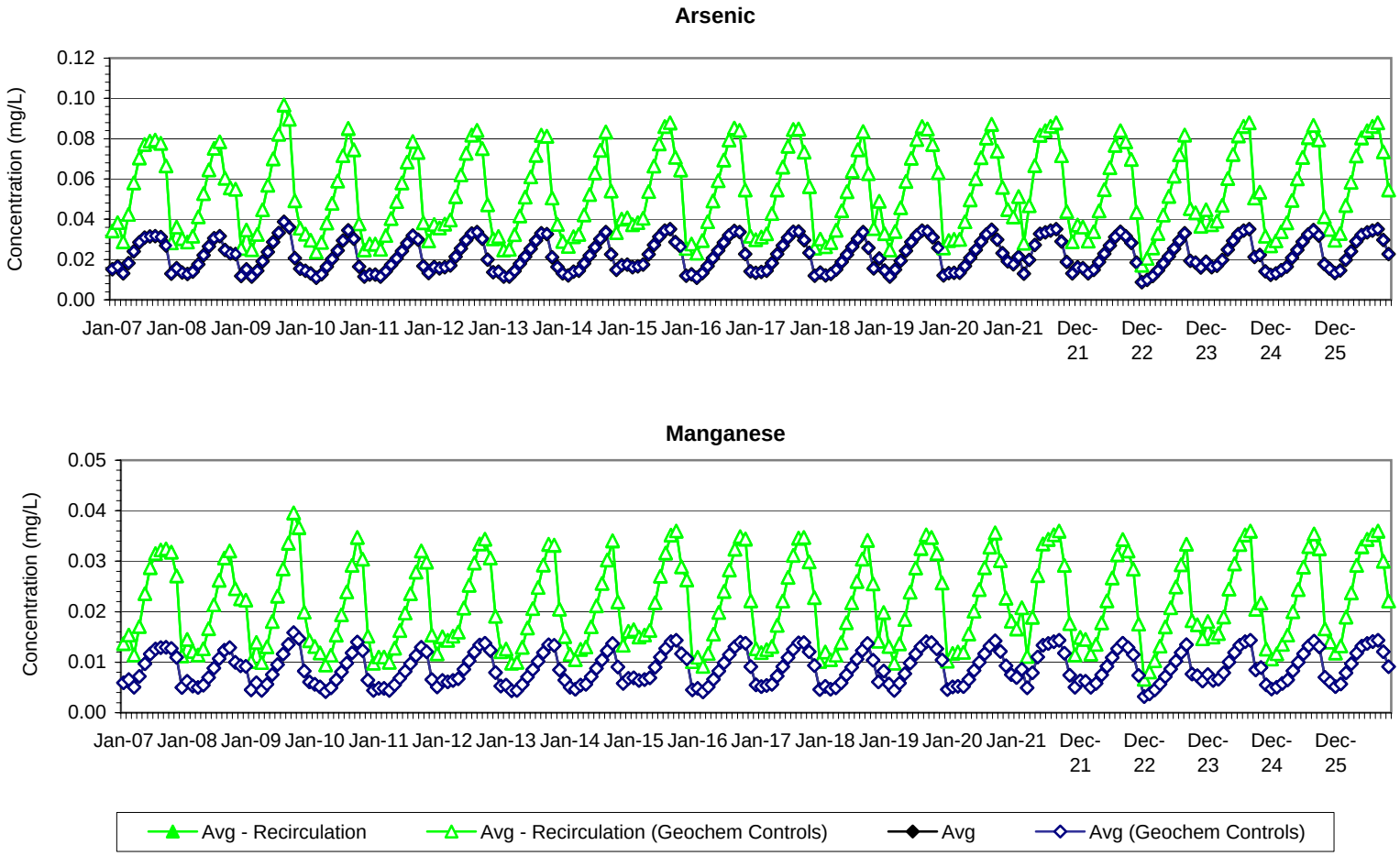
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 216 Ha Recirculation Simulation Sulfate and Calcium Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha Recirc (V2).xls	FIGURE NO.	6.5-32



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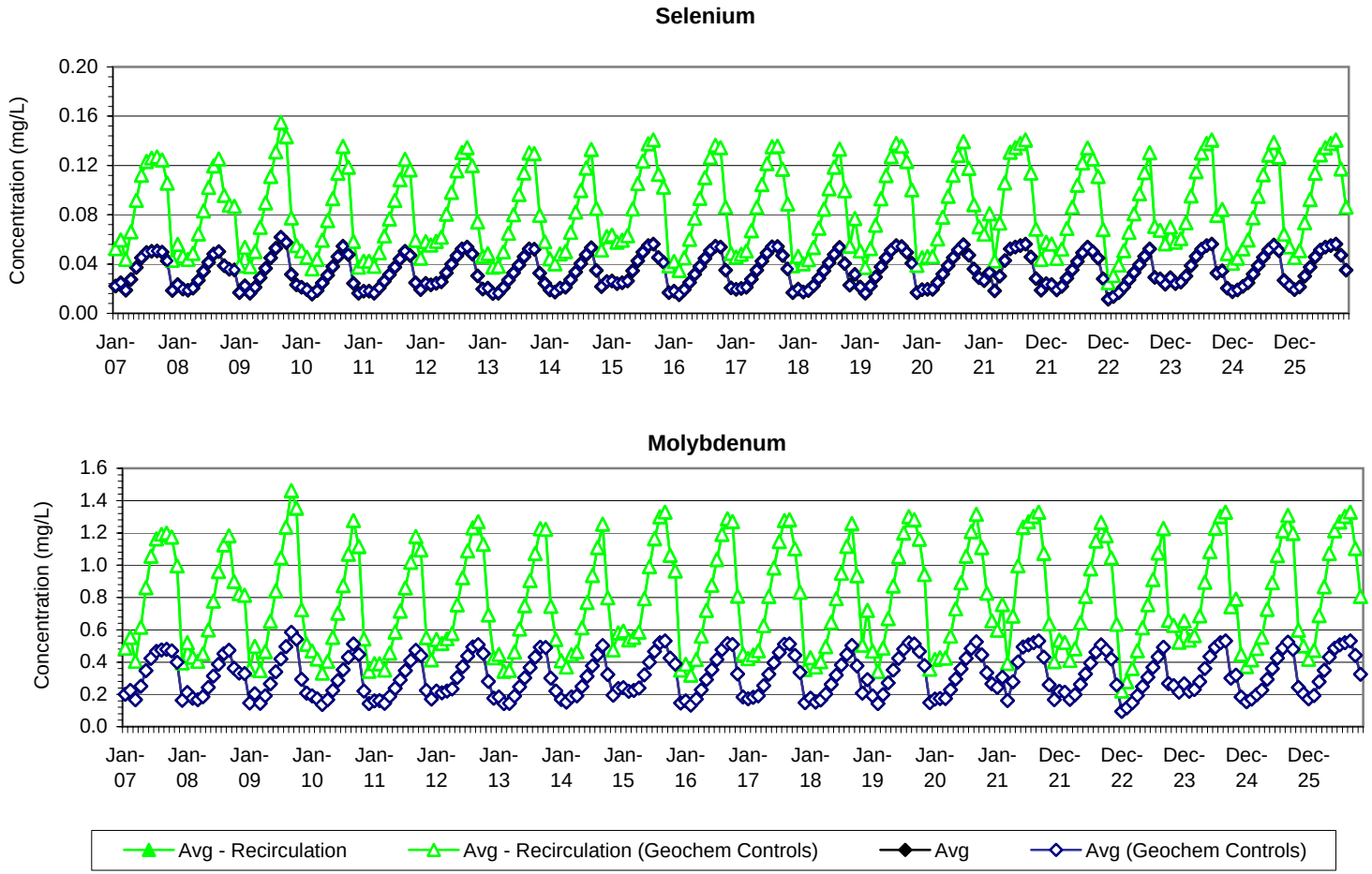
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 216 Ha Recirculation Simulation Arsenic and Manganese Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha Recirc (V2).xls	FIGURE NO.	**6.5-33**



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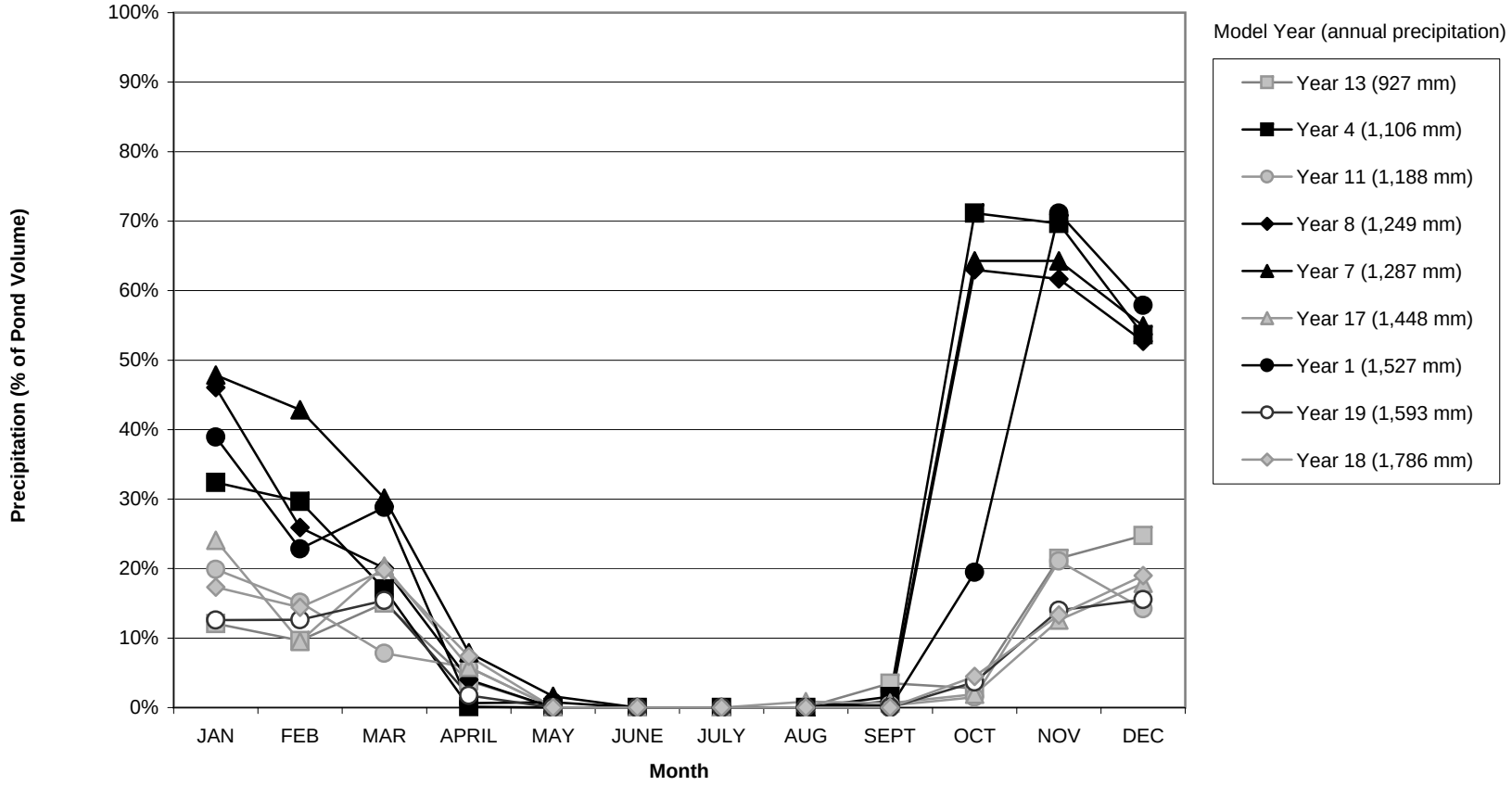
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond - 216 Ha Recirculation Simulation Selenium and Molybdenum Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha Recirc (V2).xls	FIGURE NO.	**6.5-34**



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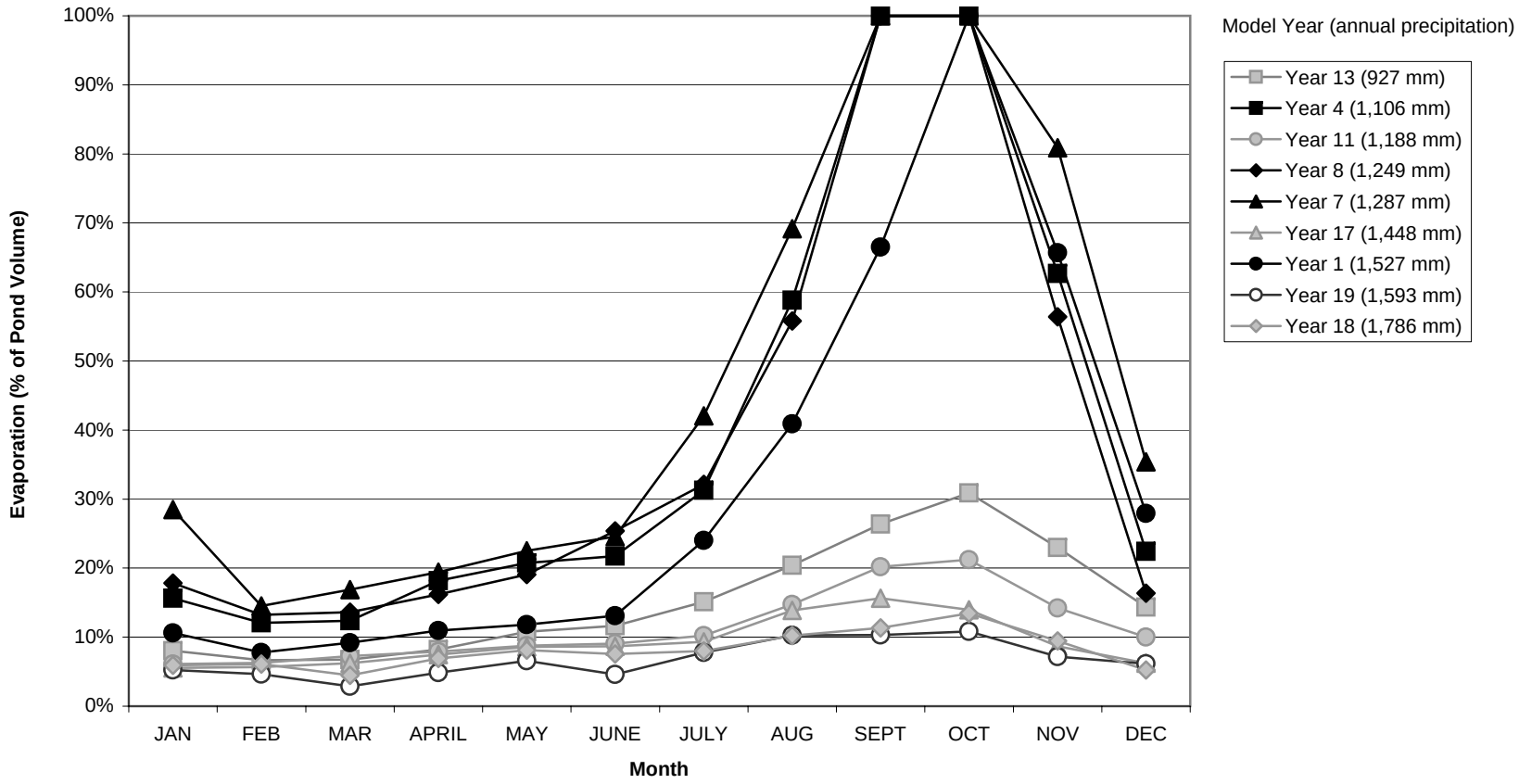
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Closure TSF Water Balance - Pond Precipitation

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Closure Water Balance.xls	FIGURE NO.	**6.5-35**



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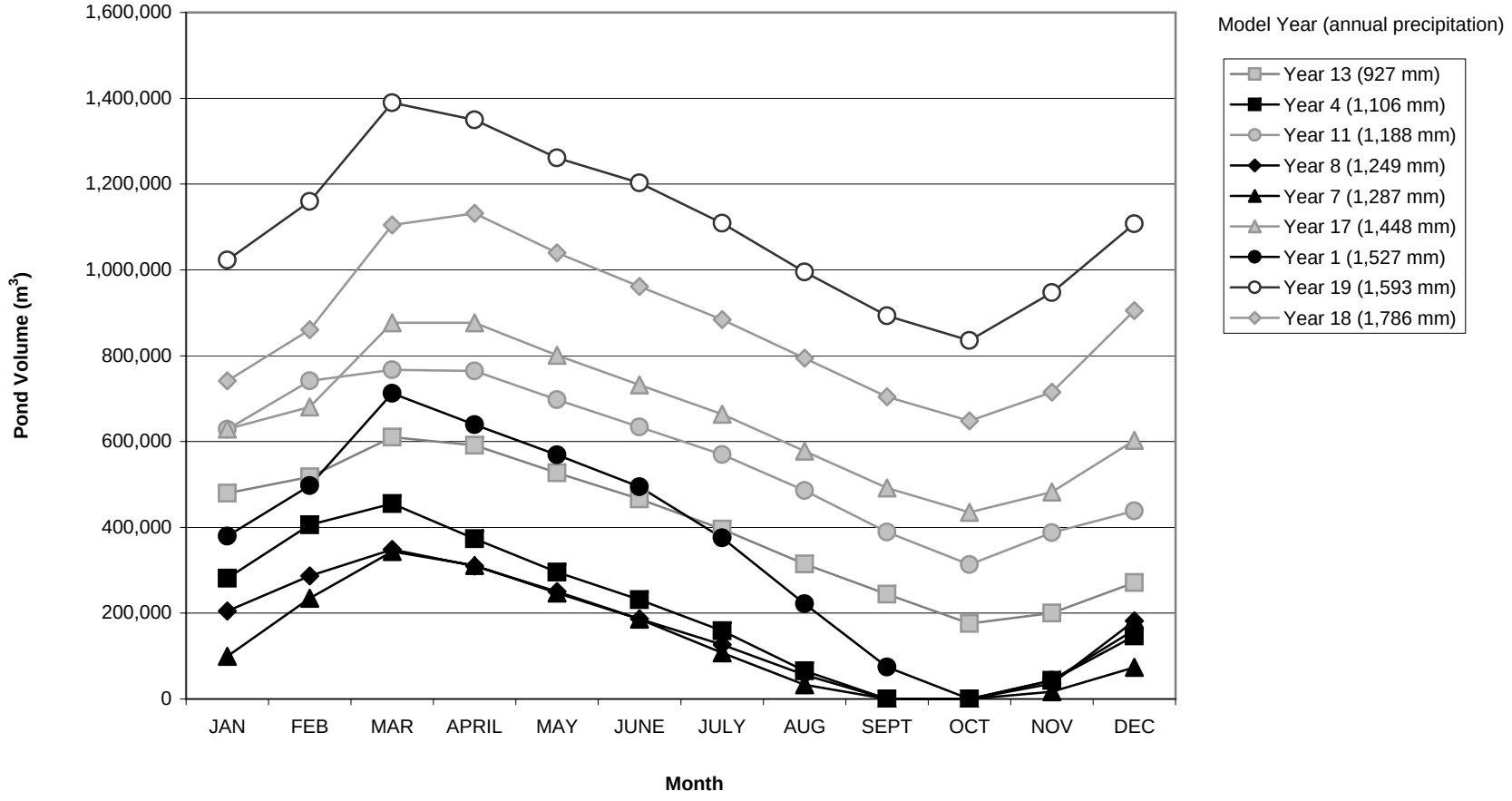
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Closure TSF Water Balance - Pond Evaporation

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Closure Water Balance.xls	FIGURE NO.	**6.5-36**



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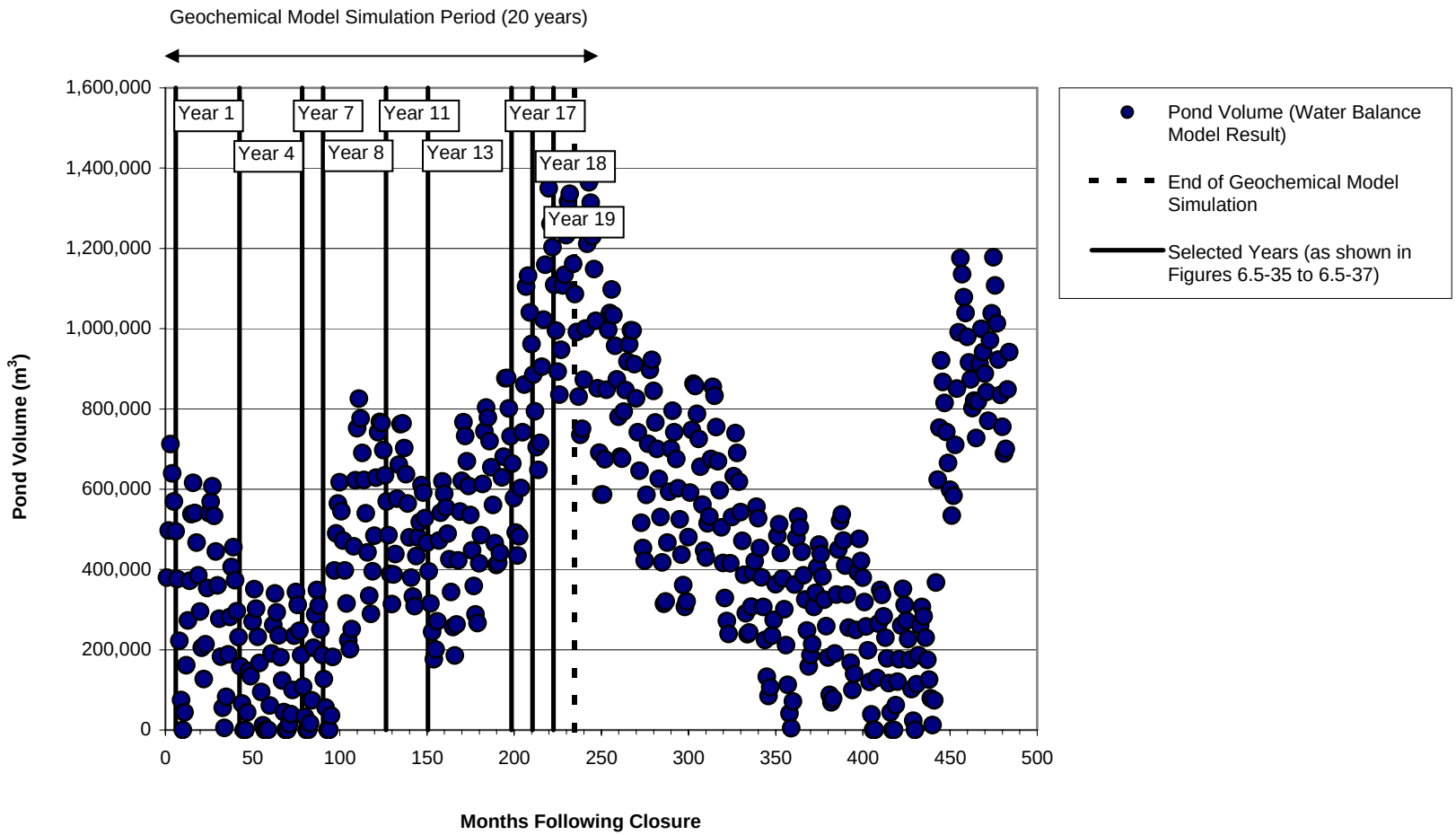
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Closure TSF Water Balance - Pond Volume

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Closure Water Balance.xls	FIGURE NO.	**6.5-37**



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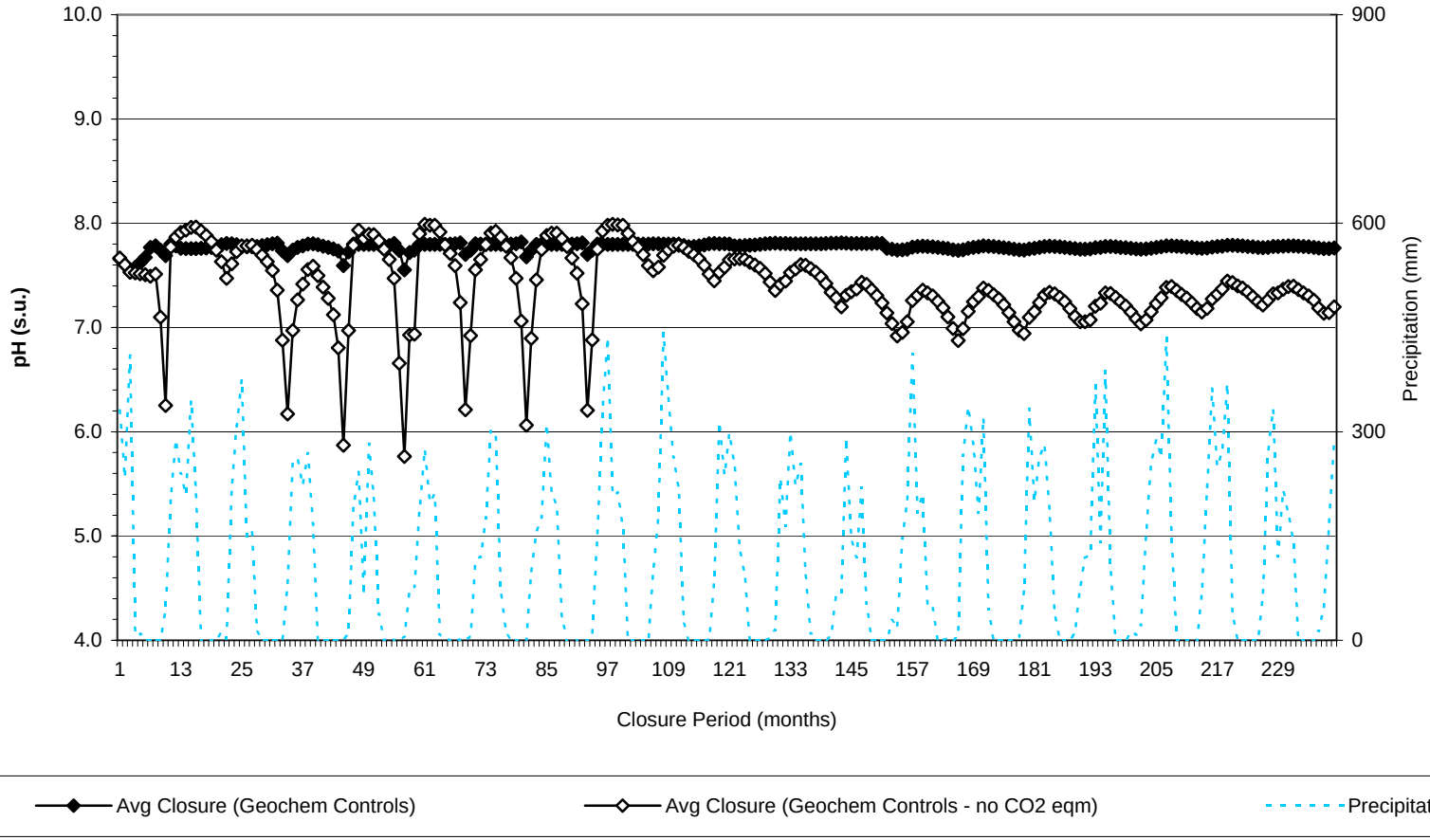
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Closure TSF Water Balance - Temporal Change in Pond Volume

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Closure Water Balance.xls	FIGURE NO.	**6.5-38**



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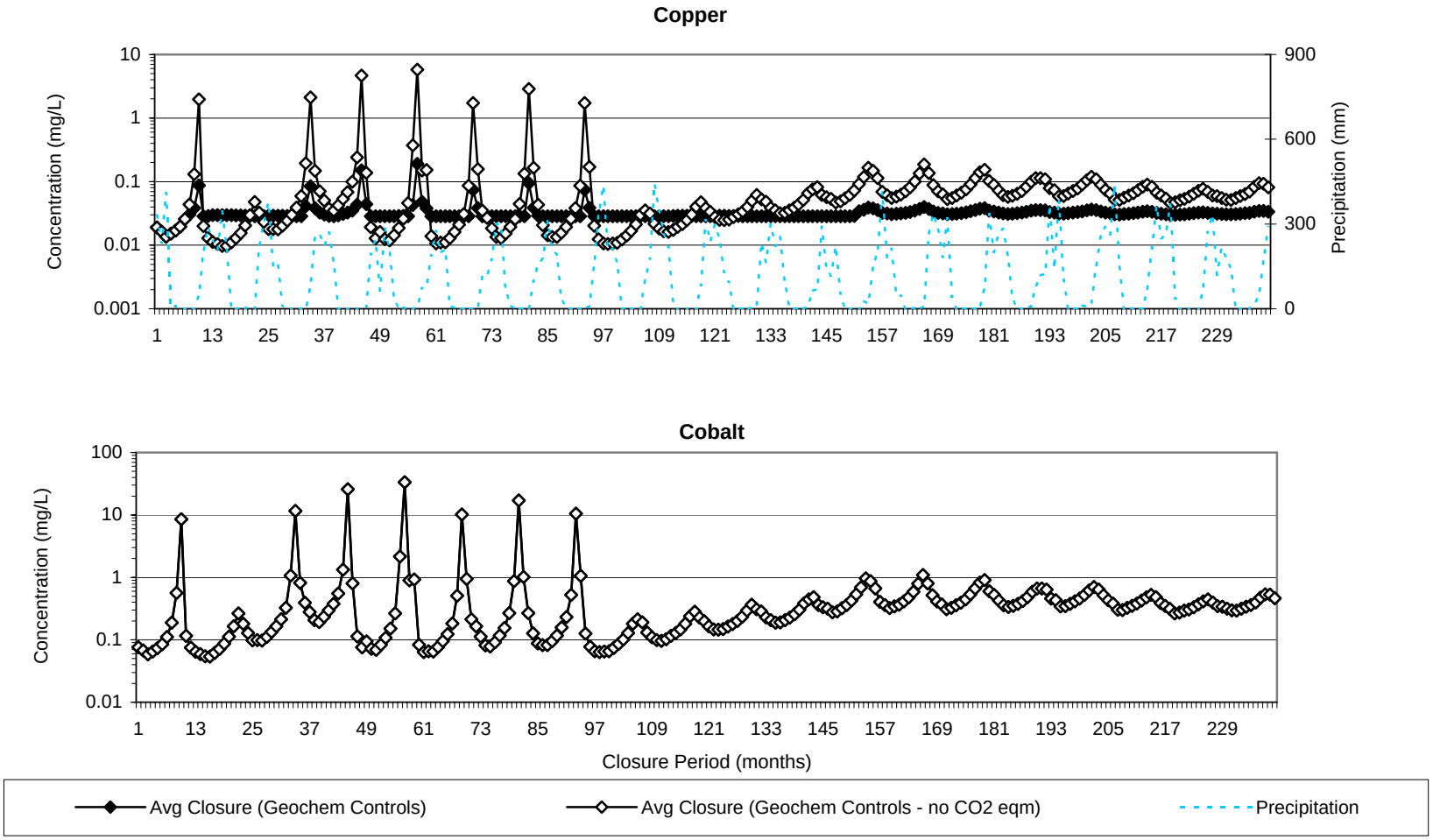
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond Closure Model Simulation - pH

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha Closure.xls	FIGURE NO.	**6.5-39**



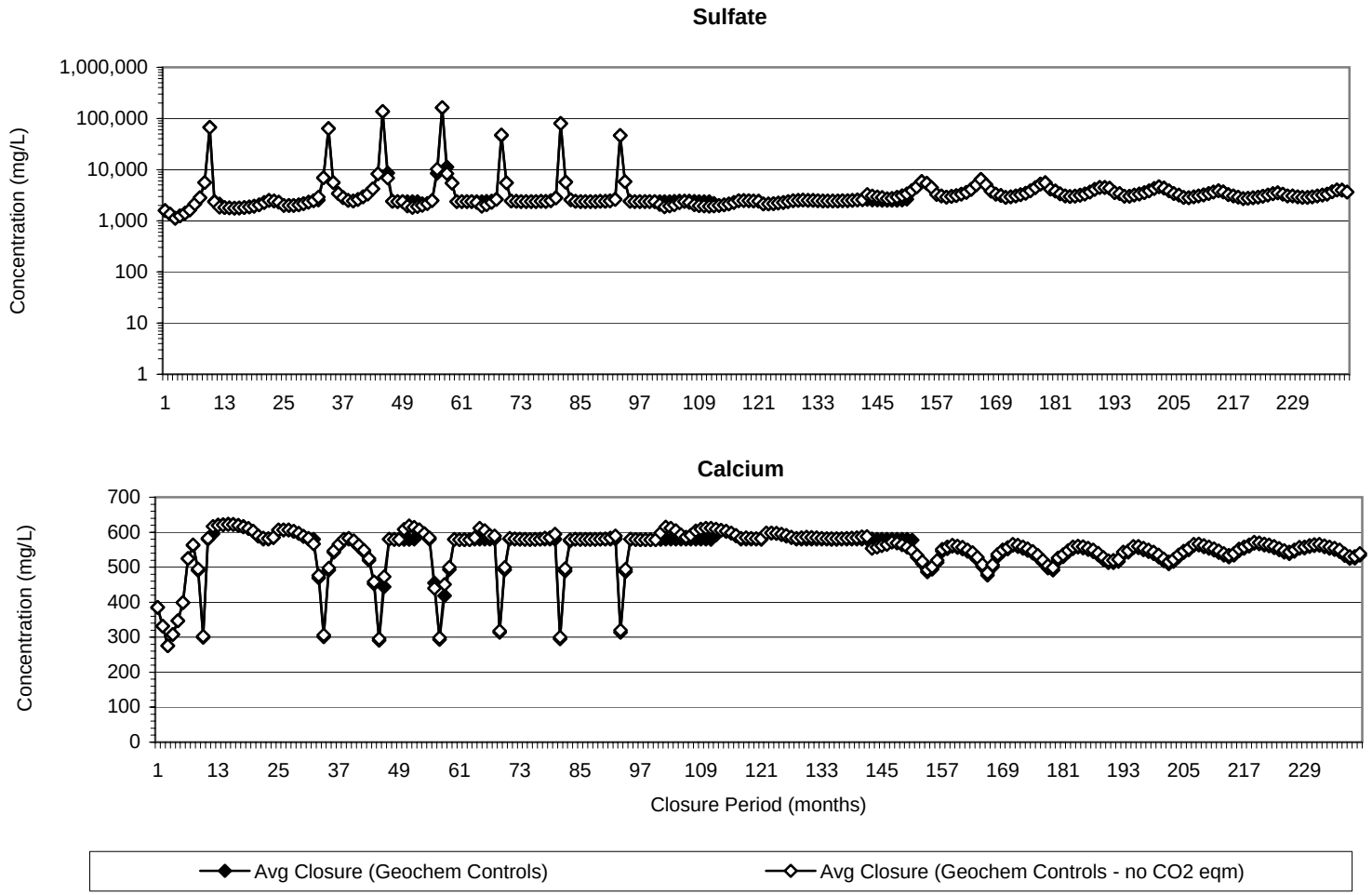
Golder Associates

Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond Closure Model Simulation - Copper and Cobalt Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha Closure.xls	FIGURE NO.	**6.5-40**



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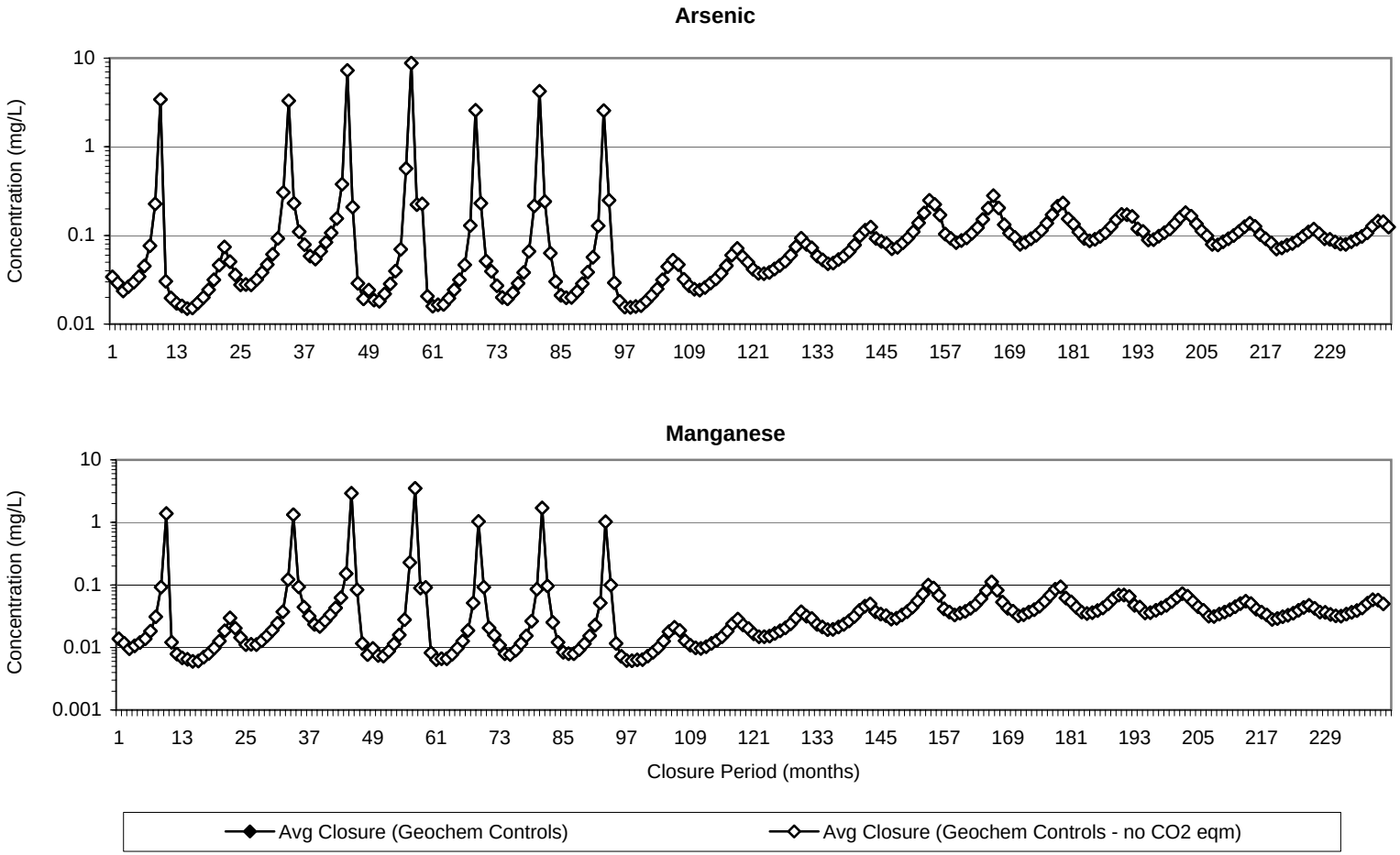
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond Closure Model Simulation - Sulfate and Calcium Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha Closure.xls	FIGURE NO.	**6.5-41**



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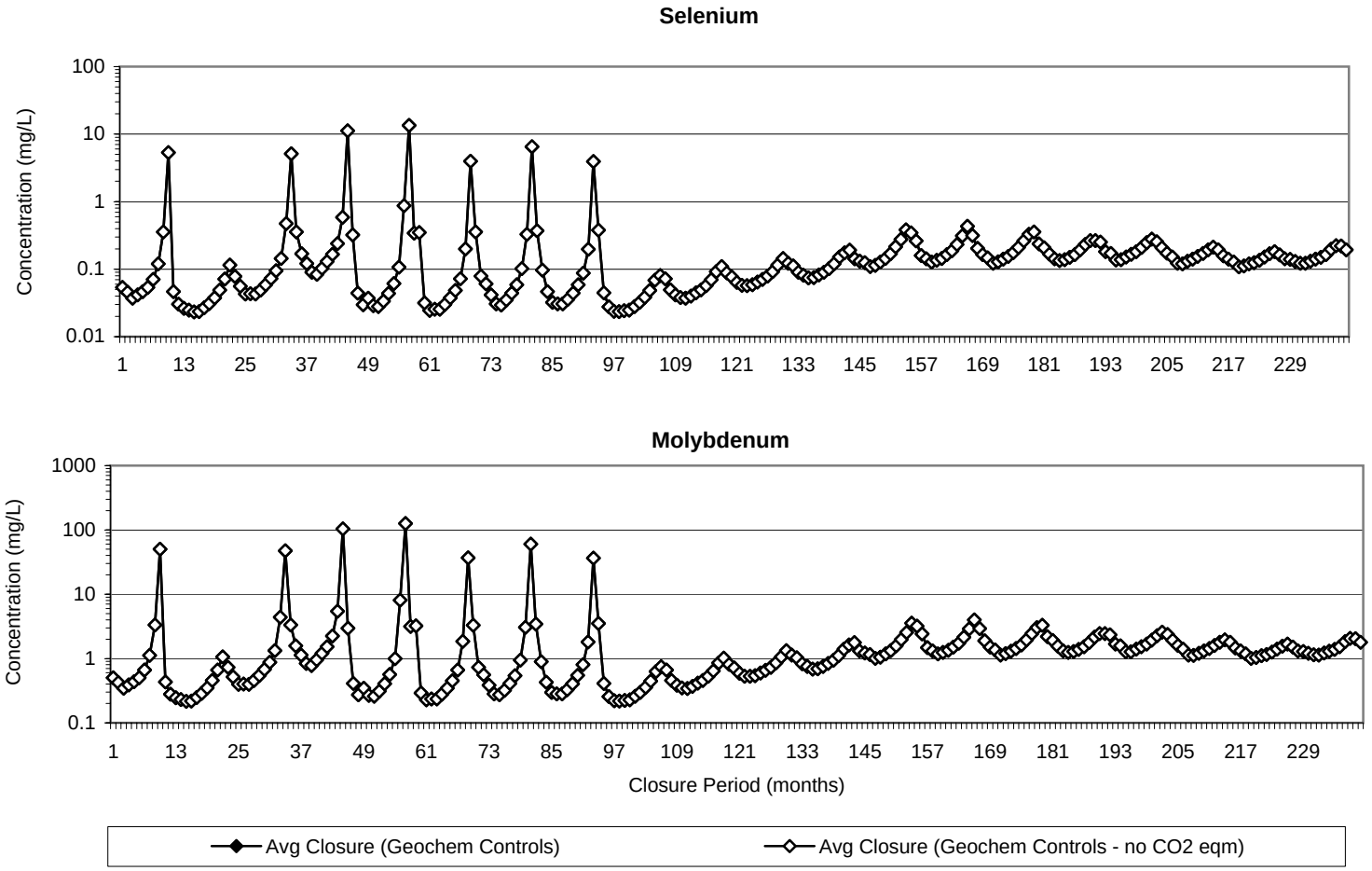
Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond Closure Model Simulation - Arsenic and Manganese Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha Closure.xls	FIGURE NO.	**6.5-42**



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Tenke Fungurume Mining S.A.R.L. (TFM)

TITLE

Tailings Pond Closure Model Simulation - Selenium and Molybdenum Concentrations

DRAWN	CR	DATE	Mar-07	JOB NO.	U04-1334
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Tenke - Tailings Model - 216Ha Closure.xls	FIGURE NO.	**6.5-43**

ATTACHMENT A

RADIOACTIVITY TECHNICAL MEMORANDUM

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Fax: (303) 985-2080
www.golder.com

TECHNICAL MEMORANDUM

TO:	Cheryl Ross, Golder – Seattle Rens Verburg, Golder – Seattle	**DATE:**	December 20, 2006
FR:	Kevin W. Conroy, P.E.	**OUR REF:**	U51334035
RE:	**TENKE PROJECT** **RADIOACTIVITY REVIEW**		

INTRODUCTION

Radioactive contaminants at mines or mineral processing and manufacturing facilities are often overlooked. Such omissions may occur because the radioactivity is unexpected or because the principal mineral(s) being mined or processed were not suspected to be radioactive. However, the geological emplacement or geothermal phenomena which formed the ore deposit may have concentrated radioactive minerals. The process of mining, beneficiation, and milling may result in a concentration or discharge of these radioactive minerals in liquid effluents or solid residues. Previous studies (Knight Piesold, 1998) have identified that the ore body and waste rock at Tenke are expected to have elevated uranium concentrations relative to crustal values due to natural enrichment. Stakeholders for the Tenke project have identified radiation as a concern for the project as well. The basis for the concern is that there was once a uranium mine within 50 km of the proposed Tenke project site, and that the mining process at Tenke may liberate uranium or other radioactive elements and increase radioactivity in soils, sediments, surface water and/or groundwater. Part of the scope of this ESIA is to determine whether there is a valid linkage between mine operations and radioactivity, and whether additional characterization or mitigation methods require development and implementation.

SAMPLING RESULTS

Multiple samples of materials to be produced or managed for the project including ore, tailings, waste rock and tailings decant water were collected for geochemical characterization, and both liquid and solid phase analysis completed. The results of these analyses specifically for radionuclides are summarized in Table 1.

EVALUATION – WATER

Screening Criteria

The World Health Organization (WHO) has developed Drinking Water Criteria for a number of radionuclides (WHO, 2006). Criteria have been established for specific uranium isotopes, as well as an overall criterion of 15 µg/L for uranium in drinking water. A gross alpha criterion of 0.5 Bq/L (13.5 pCi/L) and a gross beta criterion of 1 Bq/L (27 pCi/L) are also provided.

Table 1
Radioactivity Characterization Sampling Results

Sample	Uranium (mg/L)	Thorium (mg/L)	Alpha (Bq/L)	Beta (Bq/L)	Comments
Liquid Phase Samples					
Flume Test Overflow	0.0008	<0.0001	0.61±0.28	0.73±0.14	pH = 8.3
Column Leach Test	<0.0001	<0.0001	-	-	Average of 10 samples
Ore SPLP	<0.0001	<0.0001	-	-	Bulk upper, Average of 2 samples
Tailings SPLP	<0.0001	<0.0001	-	-	Bench upper, Average of 2 samples
Tailings SPLP	0.001	0.0001	-	-	Bulk upper, 1 sample
Tailings Decant	0.014/0.015	0.0002	0.41±0.23	0.43±0.09	pH = 2.6 Total/Dissolved
Tailings Decant	0.0016/0.0019	<0.0001	-	-	pH = 8.05 Total/Dissolved
Tailings Decant	0.0003/0.00003	<0.0001	<0.28	<0.28	pH = 8.11 Total/Dissolved
Waste Rock SPLP	<0.001	<0.001	-	-	Average of 8 samples
Solid Phase Samples					
	(µg/g)	**(µg/g)**	**(Bq/L)**	**(Bq/L)**	
Ore XRF	4.1	5.0	<0.20	1.4±0.2	Bulk upper, Average of 2 samples
Flume Test Underflow	1.1	3.2	0.9±0.33	1.4±0.2	Average of 2 samples
Tailings	1.2	2.2	-	-	Bulk upper, Average of 2 samples
Waste Rock XRF	4.6	5.5	-	-	Average of 6 samples
Waste Rock DNC	3.14	4.69	-	-	Average of 6 samples

The U.S. Environmental Protection Agency (USEPA) has developed Maximum Contaminant Limits (MCLs) for radionuclides in drinking water (USEPA, 2000). The uranium criterion is 30 µg/L, and the gross alpha criterion is 15 pCi/L. The gross alpha criterion specifically excludes contributions for uranium and radon. The gross beta criterion is dose-based at 4 mRem/yr. A screening value of 50 pCi/L (1.9 Bq/L) is used to evaluate the need for a detailed isotopic analysis and dose assessment.

Both the WHO and USEPA criteria will be used for environmental evaluation purposes.

Uranium

As shown in Table 1, uranium concentrations in samples for tailings decant, and leachates from ore, tailings and waste rock, range from <0.0001 mg/L (0.1 µg/L) to 0.015 mg/L (15 µg/L). All of the results are well below the WHO criterion of 15 µg/L and the USEPA criterion of 30 µg/L with the exception of the tailings decant water at a pH of 2.6. This stream is not actually discharged to the environment. Rather it is neutralized to a final pH of >9. As shown by the data, at this pH, residual uranium in the liquid phase is well below both the WHO and USEPA criteria.

Gross Alpha

As noted, the gross alpha criterion of 15 pCi/L from USEPA excludes contributions from uranium and radon. The analytical results (mass basis in mg/L) from Table 1 for uranium were converted to the same basis as the criterion (activity basis in pCi/gr) using a specific activity value of 0.9 pCi/µg. The specific activity conversion for uranium depends on the specific ratio of each of the uranium isotopes. A commonly used value in industry is 0.67 pCi/µg. The more conservative value of 0.9 pCi/µg was used as this is the factor used by the USEPA (USEPA, 2001) in developing their discharge criteria. The factor for converting Bq/L to pCi/L is 27 pCi/Bq (LANL, 2001). The results of the calculations are presented in Table 2.

Table 2
Gross Alpha Criteria Comparison Values, Water

Sample	pH	Uranium		Alpha		
		(mg/L)	(pCi/L)	(Bq/L)	(pCi/L)	Adjusted (pCi/L)
Flume Test Overflow	8.3	0.0008 [1/]	0.72	0.61±0.28	16.5	15.8
Tailings Decant	2.6	0.014 [2/]	12.6	0.41±0.23	11.1	~0
Tailings Decant	8.05	0.0016 [2/]	1.44	-	-	-
Tailings Decant	8.11	0.0003 [2/]	0.27	<0.28	<7.6	7.3

[1/]Dissolved
[2/]Total

The adjusted gross alpha concentrations for the tailings decant samples at pH 2.6 and 8.11 easily meet both the WHO and USEPA criteria of 13.5 pCi/L and 15 pCi/L, respectively. However, the gross alpha value for the flume test overflow is inconsistent with the rest of the data. Based on the source of the samples, the flume test overflow results at pH 8.3 should be between the tailings decant results at pH 8.05 and 8.11. This is observed for uranium, but not for gross alpha.

Acid leaching is a common method to recover uranium from ore (Merritt, 1971). In the Tenke system, uranium present in the ore will be dissolved in the pregnant liquor at the low pH of approximately 2.6. As the pH is increased in the tailings neutralization step, virtually all of the uranium (as well as thorium and radium) will precipitate and report to the solid phase. The tailings decant samples exhibit this behavior; there is an approximate 98% (i.e., greater than one order of magnitude) reduction in uranium concentration as the pH is raised from 2.6 to over 8. The measured uranium concentration in the flume test overflow sample at pH 8.3 is also consistent with this expected behavior, and the gross alpha concentrations between pH 2.8 and 8.11 exhibit a decreasing trend.

Several observations have been made with respect to the inconsistent gross alpha measurement for the flume overflow sample. The reported uranium concentration of 0.0008 mg/L in the flume test overflow sample is for dissolved uranium. Therefore, this sample would have been filtered prior to analysis. However, the analytical protocol for a gross alpha measurement involves evaporation of a non-filtered sample (USEPA, 1980). At the flume test pH of 8.3, the majority of the uranium would have to be present as a precipitated solid. As such, any solids carryover of uranium in the flume overflow would have been detected in the non-filtered gross alpha measurement, but not in the filtered dissolved uranium measurement. Therefore, the high gross alpha value in excess of WHO and USEPA criteria may be in error. In actual practice, any solids carryover from the process to the tailings facility will have significant settling time, and carryover of significant suspended solids is unlikely.

Gross Beta

As shown in Table 1, gross beta in samples for tailings decant, and leachates from ore, tailings and waste rock, ranges from <0.28 Bq/L to 0.73 Bq//L. All of these are well below the WHO criterion of 1 Bq/L and the USEPA criterion of 1.9 Bq/L.

EVALUATION – SOLID RESIDUES

Screening Criteria

Solid residues on the project will include ore stockpiles, waste rock and tailings. Applicable criteria for evaluation purposes are the soil cleanup criteria established for uranium facility remediation and closure by the USNRC and USEPA.

The USNRC has developed multiple criteria documents (USNRC, 1974; USNRC, 1981; USNRC, 1983; USNRC, 1999). These criteria are generally dose-based rather than numerical, although several specific criteria are provided for uranium and thorium. Several of the references provide a specific uranium criterion of 10 pCi/gr. Several higher limits are also provided, but are dependent on the specific form of the uranium. Likewise, several criteria are provided for thorium including 10 pCi/gr and 50 pCi/gr. Finally, a radium criterion is established at 5 pCi/gr for surface soils (first six inches), and 15 pCi/gr for subsurface soils.

The USEPA has also developed criteria documents, primarily related to the remediation of closed sites that formerly handled radioactive materials (USEPA, 1983; USEPA, 1997; USEPA, 1998). Similar to the USNRC, many of the criteria are dose-based, and a specific uranium criterion is not established in the USEPA references. Also similar to the USNRC, a 5 pCi/gr radium criterion is

provided. In addition, guidance is provided that suggests the use of 5 pCi/gr as a total radium/thorium criterion.

Since many of the USNRC and USEPA guidance documents discuss the use of dose-based assessment, a general literature search was conducted to identify the typical range of site-specific limits based on estimated dose. These assessments use computer simulations that factor site specific data and exposure pathways. The most common model is known as RESRAD. A total of eight projects were reviewed (Ashtabula; FUSRAP; Bayo Canyon; RSALOP; WDOH, 1997; Peterson, 2001; Fluor, 2005). Uranium criteria range from 35 pCi/gr to 850 pCi/gr, and thorium criteria from 2.8 to 14 pCi/gr.

Based on this review, a uranium criterion of 10 pCi/gr, a radium criterion of 5 pCi/gr and a thorium criterion of 10 pCi/gr will be used for screening purposes. There are no gross alpha or gross beta criteria for soil.

Uranium and Thorium

In order to allow for a direct comparison to the 10 pCi/gr uranium and 10 pCi/gr thorium criteria, the analytical results (mass basis in ppm, or mg/kg) from Table 1 for uranium and thorium were converted to the same basis as the criteria (activity basis in pCi/gr) using a specific activity value of 0.9 pCi/µg for uranium and 0.22 pCi/µg for thorium (USDOT). The results of the calculations are presented in Table 3.

Table 3
Summary of Uranium and Thorium Concentrations

Sample	Uranium		Thorium	
	(mg/kg)	(pCi/gr)	(mg/kg)	(pCi/gr)
Ore, bulk upper, XRF	4.1	3.70	5.0	1.1
Flume Test Underflow	1.1	0.99	3.2	0.7
Tailings, bulk upper	1.2	1.08	2.2	0.5
Waste Rock XRF	4.6	4.14	5.5	1.2
Waste Rock DNC	3.14	2.83	4.69	1.03

All of the concentrations are well below the 10 pCi/gr screening criteria for both uranium and thorium.

Radium

Radium data is available for waste rock samples, as activity for radium-226 and radium-228. Four of six samples had activity values reported for Ra-226 while one of six samples had a reported value for activity of Ra-228. Two of the four Ra-226 activities were reported at levels below the minimum detectable activity (MDA), and the one value for Ra-228 was also reported below its MDA. In order to allow for a direct comparison to the 5 pCi/gr radium criterion, the analytical results reported as Ra-226 and Ra-228 activity in becquerels per kilogram (Bq/kg), were converted to the same basis as the criteria (activity basis in pCi/gr) using conversion factors for Bq to pCi, and kilograms to grams. The results of the unit conversion for radium activity are presented in Table 4.

Table 4
Summary of Radium-226 and Radium-228 Activities in Waste Rock Samples

Sample	Radium-226 (avg of 4 samples)		Radium-228	
	(Bq/kg)	(pCi/gr)	(Bq/kg)	(pCi/gr)
Waste Rock DNC	28.6	0.77	52.6	1.42

All of the activity values for radium in waste rock are well below the 5 pCi/gr screening criteria.

Radium data is not available for either tailings or bulk ore. Radium will be present in both these solids as thorium-232 is the parent of radium-228 and thorium-230 is the parent of radium-226. Since ore and waste rock are geologically similar with the exception of mineralization, radioisotopic equilibrium relationships must be the same between rock types. Table 4 uranium and thorium concentrations are similar to the upper bulk ore sample (XRF data) and both the waste rock samples (by XRF and DNC). Since the measured radium concentrations for the waste rock sample by DNC is well within established criteria, this conclusion also applies to bulk ore. Uranium and thorium concentrations in tailings samples are lower than both the bulk ore and waste rock concentration; and compliance with radium criteria in these samples would be expected as well.

CONCLUSIONS

Two different scenarios exist for release of radioactivity to water resources. The first is process water in the form of tailings decant water that could be released to the environment due to overflows, spills, emergency discharge, or planned discharge. Analysis of the decant water as a function of pH demonstrates compliance with criteria for uranium, gross alpha and gross beta. The SPLP data for tailings indicates that leaching of radioactive constituents is unlikely. However, it is still possible that, with tailings recycle over an extended period of time, the concentration of radioactive species (as well as other dissolved species) could increase in the tailings decant and Return Water Dam. An on-going sampling program of the tailings decants and Return Water Dam flow for uranium, gross alpha and gross beta is recommended. If concentrations begin to increase, appropriate temporary treatment measures may be warranted.

The second potential water resource impact is to surface water or groundwater due to run-off and seepage through waste rock dumps and ore stockpiles. The leach test and SPLP results indicate that this impact is unlikely. General segregation and diversion of surface water flows from stockpiles and waste rock is still a good overall management practice, and is recommended.

Analysis for uranium and thorium in the ore and waste rock suggests that special precautions and permitting for the stockpiles and waste rock dumps will not be necessary. Release of significant quantities of radioactive constituents from tailings to the decant water and Return Water Dam is also unlikely provided the pH remains high. Due to the continuous deposition of tailings, the total mass of radioactive constituents per unit volume of tailings should not significantly increase. It is possible that at closure that enough uranium and it's daughter products could be present in the tailings to release measurable radon. A monitoring program during tailings facility operations and at closure will determine if this is an issue. If radon is present, standard cover technologies are available to eliminate this hazard.

While the environmental risk associated with solid phase residuals appears to be low, implementation of an on-going monitoring program is recommended. This program should include routine sampling of tailings for uranium, radium, and thorium. As the tailings facility is loaded, additional field sampling using radon canisters is also recommended.

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Golder Associates	SUBJECT Tenke Fungurume Radioactivity Review		
	Job No. U51334035 Ref.	Made by PRLemke Checked KW Conroy Reviewed KW Conroy	Date 18 Dec 06 Sheet 1 of 4

Objective:

1. Review revised radioactivity data for waste rock.
2. Compare radioactivity data to existing regulatory criteria for US agencies and the World Health Organization (WHO) for water and residual solids
3. Determine whether these are significant environmental concerns with respect to radioactivity

Radioactivity Data - Analytical Lab report for waste rock analysis by delayed neutron counting for U and HPGe gamma detection for thorium

Sample ID	U (µg/g)	Th (µg/g)
RAT oxidized	4.98	12.1
SPS oxidized	3.24	4.23
RSC oxidized	1.26	2.1
RSF sulfur	4.41	3.73
RSC sulfur	0.712	0.749
SPS sulfur	4.24	5.24
Avg of six samples	3.14	4.69

Environmental Criteria - USNRC, USEPA, site-specific cleanup goals - All as previously documented (Tech memo dated 7/20/06)

FOR RESIDUES
Radium - use 5 pCi/g
Uranium - use 10 pCi/g
Thorium - use 10 pCi/g

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Evaluation - Waste Rock

URANIUM

uranium screening criteria is 10 pCi/g. Convert mass concentration as follows

$$U\ (\mu g/g) \times 0.9\ \frac{pCi}{\mu g} = U\ pCi/g$$

Sample	U (µg/g)	U (pCi/g)	% of criterion
RAT-ox	4.98	4.48	45 %
SPS-ox	3.24	2.92	29 %
RSC-ox	1.26	1.13	11 %
RSF-sulfur	4.41	3.97	40 %
RSC-sulfur	0.712	0.64	6 %
SPS-sulfur	4.24	3.82	38 %
waste rock avg U	3.14	2.83	28 %

All individual sample results and the average of six waste rock samples are all less than 50% of the screening value.

Thorium

Thorium screening criteria is 10 pCi/g. Convert mass concentrations as follows:

$$Th\ (\mu g/g) \times 0.22\ pCi/\mu g = Th\ (pCi/g)$$

Sample	Th (µg/g)	Th (pCi/g)	% of criterion
RAT-ox	12.1	2.66	27 %
SPS-ox	4.23	0.93	9 %
RSC-ox	2.1	0.46	5 %
RSF-sulfur	3.73	0.82	8 %
RSC-sulfur	0.749	0.16	2 %
SPS-sulfur	5.24	1.15	12 %
Waste rock avg Th	4.69	1.03	10 %

Golder Associates	SUBJECT Tenke Fungurume Radioactivity Review		
	Job No. U51334035 Ref.	Made by PR Lemke Checked KW Conroy Reviewed KW Conroy	Date 18 Dec 06 Sheet 3 of 4

Radium

Radium screening value is 5 pCi/g

Ra 226 / Ra 228

Ra 226

Sample	activity Bq/kg
RAT-ox	27.7
SPS-ox	—
RSC-ox	46.4
RSF-sulfur	62.1
RSC-sulfur	—
SPS-sulfur	35.3
waste rock avg	28.6

convert Bq/kg to pCi/g

multiply Bq by 27 to obtain pCi

$$(Bq/kg)\left(\frac{27\ pCi}{Bq}\right)\left(\frac{kg}{1000\ g}\right) = pCi/g$$

SAMPLE	Ra 226 activity (pCi/g)	% of CRITERION
RAT-ox	0.748	15%
SPS-ox	—	0
RSC-ox	1.25	25%
RSF-sulfur	1.68	34%
RSC-sulfur	—	0
SPS-sulfur	0.953	19%
waste rock avg	0.77	15%

All individual sample results and the avg for all waste rock samples are less than 35% of the screening value for Ra

Golder Associates	SUBJECT Tenke Fungurume Radioactivity Review		
	Job No. U513344035 Ref.	Made by PR Zenka Checked KW Conroy Reviewed KW Conroy	Date 18 Dec 06 Sheet 4 of 4

Ra 228

Sample	Activity (Bq/kg)	Activity (pCi/g)
RAT-OX	52.6	1.42
SPS-OX	—	
RSC-OX	—	
RSF-Sulfur	—	
RSC-Sulfur	—	
SPS-Sulfur	—	

Adding activity for RAT-OX sample for Ra 226 and Ra 228 gives 2.17 pCi/g - still less than half of the screening value for Ra 226/Ra 228

All individual and additive results for Ra 226/Ra 228 are less than 50% of the screening value

The average value for Ra 226 is also less than the screening value

The individual result for Ra 228 is less than the screening value

References: Technical Memorandum - Tenke Project Radioactivity Review, July 28, 2006

Calculations supporting the Tech Memo by K Conroy, dated July 20, 2006

Radio Analysis Laboratory - Final Report for Job Code RA 07429

1. SERVICE SUMMARY

Six solid samples were received for analysis of their radioactivity content. The radionuclides of interest are NORM's (Naturally Occurring Radioactive Materials) and typically include Uranium (^{238}U, ^{235}U), thorium (^{232}Th, ^{228}Th), radium (^{228}Ra, ^{226}Ra), as well as ^{210}Pb and ^{40}K. Besides the nuclide-specific analyses, the samples were also analysed for their gross activity content.

2. SAMPLE RECEIVED

The samples were received for analysis on Thursday, 20 July 2006. The samples were coded for laboratory use, both field description and laboratory code are reported.

Sample Mark	Necsa code	Field description	Sample material	Sample Condition
RAT OXIDIZED	7429x001	77513	Solid	Good
SPS OXIDIZED	7429x002	77514	Solid	Good
RSC OXIDIZED	7429x003	77515	Solid	Good
RSF SULPHUR	7429x004	77516	Solid	Good
RSC SULPHUR	7429x005	77517	Solid	Good
SPS SULPHUR	7429x006	77518	Solid	Good

3. SAMPLE PREPARATION AND ANALYSES

3.1. Initial sample preparation

(a) Dry, mill and homogenise solids

Performed by the client

3.2. Analysis of solid sample

(a) Gross αβ-activity counting of solid

Product: 030311

Performed on: 24 September 2006

Method: RA-WIN-138

Assayer: Kotie van der Waldt

The samples were adjusted to a specific sample geometry and counted on a low background gas-flow proportional counter for 5 to 6 hours per sample. Results are reported in $Bq.g^{-1}$.

(b) Uranium/Thorium analysis of solids

Product: 060331

Performed on: 25 August 2006

Method: RA-WIN-167

The sub-samples of 200 mg each were weighed out in specially designed irradiation capsule and irradiated in the SAFARI Research Reactor for 20 seconds each, together with element standards. The uranium concentration (µg/g) is determined by Delayed Neutron Counting (DNC). The samples were counted again after a cooling-off period of approximately 7 days on a well-type HPGe gamma detector for determination of the thorium concentration (µg/g). These concentration values are then converted to the respective activity concentrations ($Bq.kg^{-1}$).

(c) Radium analysis of solids

Product: 050141

Performed on: 04 September 2006

Method: RA-WIN-101

The samples were counted on a low-background high energy HPGe gamma-spectrometry system for two hours. The spectral data is analysed for the radionuclides ^{226}Ra, ^{228}Ra, ^{228}Th and ^{40}K and the activity results reported in $Bq.kg^{-1}$.

(d) ^{210}Pb analysis of solids

Product: 050221

Performed on: 23 August 2006

Method: RA-WIN-158

Sample is adjusted to a specific counting geometry for analysis on a HPGe gamma-spectrometry system with an ultra-thin beryllium window for low-energy counting. Absorption corrections are made for each sample by counting a collimated absorption source. Activity results are reported in $Bq.kg^{-1}$.

3.3 Quality Assurance

All analytical methods are validated and documented in the RadioAnalysis Quality System, which is based on ISO/IEC Standard 17025. The RadioAnalysis Laboratory is accredited for, inter alia, method RA-WIN-101 (Testing Laboratory T0111).

3.4 Data reduction and evaluation

Data is evaluated against the regulatory requirements and recommendations are made where relevant.

4. ANALYTICAL RESULTS

(a) The analytical results are presented as appendices to this report.

(b) The reported uncertainty is a probable error calculated mainly from the counting statistics, and is not the normal standard deviation on replicate analyses.

5 REMARKS AND OBSERVATIONS

5.1 Results reported only apply to samples received by RadioAnalysis. It is assumed that the sampling procedure, normally performed by the client, is representative of the source matrix. Further sample preparation done by RadioAnalysis only improves the homogeneity of the sample(s) received.

5.2 The format for reporting of results (see Appendix 1) can be explained as follows:

X: which is the measured value, and can be negative if the value is close to or even below the minimum detection limit;

Sx: the probable error, which is calculated from counting statistics and gives an indication of the uncertainty in the result (sometimes also reported as "X ± Sx");

MDA: The minimum detectable activity, which is the detection limit of the method and specific sample matrix (sometimes also reported as "< MDA").

5.3 It should be emphasised that gross αβ-activity measurements are merely meant to screen samples for their total activity. The measured activities differ from the true activity due to the energy of the α- and β-particles involved, as well as the density of the matrix concerned.

5.4 South African Nuclear Energy Act No 47 of 1999

Government Notices R8454 Vol. 490 No. 28755, 28 April 2006.

The above Government Notice classify material which is handled and processed, *i.e.* material which workers and the public will come into contact with, and which can pose a hazard to the public health, as having a specific activity of each radioactive nuclide of less than 500 Becquerel per kilogram except for Radon, below which the provisions of the Act do not apply. It should be noted that for ^{40}K the level should not exceed 10 000 Becquerel per kilogram for building material and 50 000 Becquerel per kilogram in all other material.

Nuclide-specific results for these material are significantly below the 500 $Bq.kg^{-1}$ level.

It is recommended that the National Nuclear Regulator of South Africa be consulted for further evaluation of the results, work environment and waste treatment aspects. The RadioAnalysis Laboratory is not authorised to remark on possible controls to be implemented.

5.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years. We do not take responsibility for electronic versions of this report, nor do we guarantee the correct transfer of electronic data from our laboratory to the client.

SAMPLE MARK: RAT OXIDIZED SPS OXIDIZED RSC OXIDIZED RSF SULPHUR

APPENDIX 1:

Radioisotopes:	Sample activity in Bq/kg 7429x001			7429x002			7429x003			7429x004		
	X	Sx	MDA	X	Sx	MDA	X	Sx	MDA	X	Sx	MDA
U-238 decay series												
U-238	61.5	1.8	1.1	40	1.5	1.1	15.5	0.9	1.1	54.5	1.7	1.1
Ra-226	27.7	15.8	52	-	-	53	-	-	42	62.1	12.7	37
Pb-210	-	-	110	49.6	23.8	78	46.4	17.3	56	67.4	20	63
U-235 decay series												
U-235	2.83	0.09	0.052	1.84	0.07	0.05	0.715	0.043	0.05	2.51	0.08	0.05
Th-232 decay series												
Th-232	49.1	1.2	3.4	17.2	0.6	2.3	8.53	0.93	3.7	15.1	0.8	4.1
Ra-228	52.6	24.6	79	-	-	90	-	-	73	-	-	80
Th-228	58	13.5	42	15.8	9.6	54	13.9	7.7	40	-	-	50
K-40	942	136	340	510	98	260	231	74	230	333	79	220
Gross α-activity [Bq/g]	1.1	0.14	0.33	0.909	0.132	0.32	0.277	0.102	0.31	0.993	0.135	0.32
Gross β-activity [Bq/g]	1.28	0.02	0.041	0.6	0.019	0.041	0.139	0.014	0.039	0.419	0.017	0.041
[Uranium] in μg/g	4.98	0.15	0.091	3.24	0.12	0.087	1.26	0.07	0.089	4.41	0.14	0.087
[Thorium] in μg/g	12.1	0.3	0.84	4.23	0.14	0.57	2.1	0.23	0.92	3.73	0.19	1

SAMPLE MARK : RSC SULPHUR SPS SULPHUR

APPENDIX 1:

Radioisotopes:	Sample activity in Bq/kg 7429x005			7429x006		
	X	Sx	MDA	X	Sx	MDA
U-238 decay series						
U-238	8.79	0.71	1.1	52.4	1.7	1.1
Ra-226	-	-	42	35.3	12.9	41
Pb-210	-	-	73	58.5	21.2	68
U-235 decay series						
U-235	0.405	0.033	0.05	2.41	0.08	0.049
Th-232 decay series						
Th-232	3.04	0.74	3	21.3	0.7	3.2
Ra-228	-	-	75	-	-	85
Th-228	-	-	43	-	-	50
K-40	231	75	230	522	88	230
Gross α-activity [Bq/g]	0.626	0.119	0.31	0.879	0.131	0.32
Gross β-activity [Bq/g]	0.0967	0.0133	0.04	0.545	0.018	0.041
[Uranium] in µg/g	0.712	0.058	0.088	4.24	0.13	0.086
[Thorium] in µg/g	0.749	0.182	0.74	5.24	0.18	0.78

APPENDIX B2.3-II

LIMESTONE QUARRY GEOCHEMICAL ASSESSMENT

1 INTRODUCTION

The objective of this geochemical assessment for the proposed limestone quarry site at the Tenke Fungurume Mining (TFM) project area is to evaluate the magnitude and spatial extent of possible impacts on the water quality (surface and groundwater quality) in the vicinity of the quarry arising from quarrying activities.

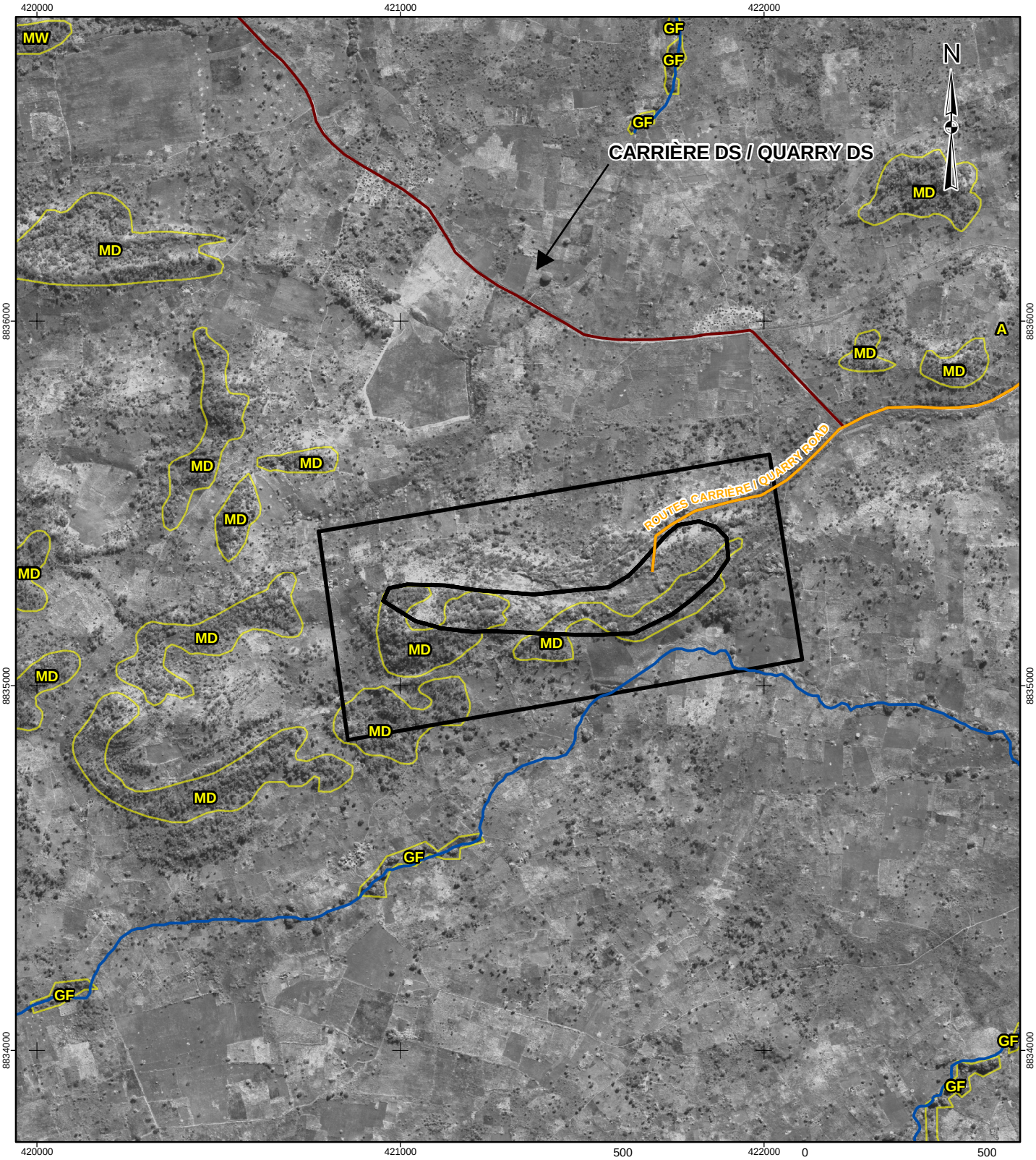
To assess possible impacts on the water quality of the receiving environment, the chemical analyses of samples from the proposed quarry limestone was used in addition to the current spring water and sediment data collected in close proximity to the proposed quarry area.

2 STUDY AREA

The regional geology comprises the Roan Series. The Upper Roan is a predominantly dolomite-argillite sequence which is succeeded conformably by carbonaceous shales, argillite and minor carbonate rocks of the Mwashia Formation. The geological formations and their lithologies are summarized in the Geology Baseline Report (Section B2.2). The limestone for the proposed quarry is found in the Mofia lithologic unit within the Upper Roan Series formation.

Figure 1 provides a detailed map of the limestone quarry disturbance area (bean shaped area) and a fence line (rectangular) and indicates the current spring sample location (Quarry DS). The sample point was considered in order to assess the current water and sediment quality of the quarry area. The water from the spring is used as drinking water. One sediment sample and one water sample were collected at the seepage point (Photograph 1) down slope of the quarry during the baseline sampling in January 2006. The high turbidity observed at the sample point can be attributed to the natural soil runoff from the heavy rainfall events.

The quarry is located on a hill and has a ridge or natural barrier (Figure 1 and Photograph 3) which will prevent runoff from exposed quarry rock entering the river located on the southern side of the limestone quarry. Photograph 2 and Photograph 3 show the physical environment of the current limestone quarry. The final quarry outline indicates that the ridge to the south will remain as a barrier and that potential impacts will remain to the north of the quarry.



420000 421000 500 422000 0 500

ÉCHELLE 1:15000 MÈTRES
SCALE 1:15000 METRES

LÉGENDE / LEGEND

- RIVIÈRE / RIVER
- ROUTE / ROAD
- ROUTES CARRIÈRE / QUARRY ROAD

COUVERTURE VÉGÉTALE / UTILISATION DU TERRAIN / LANDCOVER

- A = MOSAÏQUE AGRICOLE / AGRICULTURAL MOSAIC
- GF = FORÊT GALERIE / GALLERY FOREST
- MD = FORÊT DE MIOMBO DÉGRADÉE / MIOMBO WOODLAND DEGRADED
- MW = FORÊT DE MIOMBO / MIOMBO WOODLAND
- CARRIÈRE / QUARRY

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

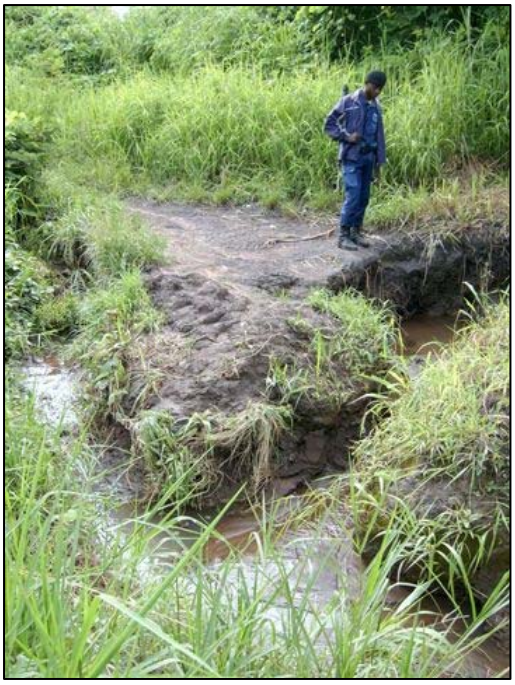
TITRE
TITLE

SECTEUR LOCAL D'ÉTUDE - CARRIÈRE /
LOCAL STUDY AREA - QUARRY

Golder Associates
Calgary, Alberta

N° projet / project no. 05-1334-035.9300			Échelle telle qu'indiquée Scale as Shown	REV. 0
DESSIN / DESIGN	GJ	20 Mar. 2006	**FIGURE: 1**	
SIG / GIS	CW	10 Jan. 2007		
VÉRIFIÉ / CHECK	MR	10 Jan. 2007		
APPROUVÉ REVIEW	MR	10 Jan. 2007		

Project I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\mxd\Vegetation\Figure1_QuarryLSA.mxd - Plot I:\CLIENTS\PHELPS_DODGE\05-1334-035\mapping\pdf\Vegetation\Figure1_QuarryLSA.pdf



Photograph 1: Quarry Downstream Sample Point on the North side of the Limestone Quarry of where the Water and Sediment Sample were taken

Photograph 2: Limestone Quarry Site in Tenke Fungurume (Looking East)

Photograph 3: Limestone Quarry Site in Tenke Fungurume (Looking South)

3 PREVIOUS WORK

Previous studies (Knight Piésold 1998) characterized the waste rock of the Middle Roan series in the proposed Kwatebala pit. All non-ore material was expected to fall into three known waste rock groups namely (1) the chloritic, dolomitic pelites (RAT) and siltstone type; (2) silicified stromatolitic dolomite type (RSC); and (3) the dolomitic shales (SDS) as defined by the lithology. Weathering of the Roan Group units in the vicinity of the TFM project was found to be pronounced, resulting in an oxidized zone which persists 100 to 150 meters below surface. The sulfide mineral abundance in this zone is likely to have been removed through historic oxidation.

The Acid Base Accounting (ABA) tests indicated no significant net potential for acid rock drainage production based on the overall dolomitic nature of the waste rock and the absence of sulfide sulfur in composite samples. The weathered nature of the waste rock in the oxide zone resulted in Synthetic Precipitation Leaching Procedure (SPLP) leachates that were below detection limits and met the drinking water standards. The leachates from the dolomitic shales were characterized as calcium and magnesium bicarbonate type waters and were found to exhibit a narrow range of compositions. The chemistry was found to be reflective of pervasive dolomite rich rock chemistry. It was concluded from the study that no leachability issues are likely to arise from exposing the Middle Roan rock material at the planned limestone quarry.

The current geochemical tests (Geochemical Baseline Report - Section 5.4.1.4) of the waste rock showed leachate pH values ranging from pH 6.2 to 9.8 hence indicating greater metal leaching potential for waste rock than the previous work. In addition to cobalt and copper, SPLP leach test results indicated enhanced leaching for the following parameters at lower leachate pHs: calcium, lead, magnesium, manganese, nickel and zinc. All leach tests indicated low leaching potential for leaching of arsenic (up to ppb levels), antimony (all <0.001 mg/L) and selenium (all <0.01 mg/L) from the oxide waste rock samples. SPLP test results for the sulfide waste samples also indicated low selenium and antimony mobility. Waste rock leach testing indicated a potential for release of aluminum, chromium, lead, manganese, molybdenum, nickel and zinc.

4 METHODS AND RESULTS

The chemical analyses of two Mofia limestone samples (51216-25a and 51216-25c) indicate that the limestone is carbonate and calcium rich and is composed of significant amounts of magnesium and silica. Table 1 provides the chemical analysis from the first round of piloting data done by Hazen Research Inc.

The quarry site was sampled in conjunction with the surface water and sediment quality field program. Sampling methods and results of analysis can be found in the Physical Baseline Report - Water and Sediment Quality (Section B2.12).

Table 1: Mineralogical analysis of Mofia limestone

Analyte	HRI	51216-25a	51216-25c
		Analysis (w/w) %	
% (w/w) Moisture	**-**	**0.11**	
Ctot	as received	11.5	11.4
	dry basis	11.5	11.5
CO32-	as received	53.4	57.4
	dry basis	53.5	57.5
Corg (by diff)	as received	0.799	<0.01
	dry basis	0.800	<0.01
Mg	as received	2.14	2.12
	dry basis	2.14	2.13
Mn	as received	0.005	0.005
	dry basis	0.005	0.005
Ca	as received	24.2	34.0
	dry basis	24.2	34.0
K	as received	0.058	0.055
	dry basis	0.058	0.055
Si	as received	1.77	1.73
	dry basis	1.77	1.74
Al	as received	0.09	0.07
	dry basis	0.09	0.07
Na	as received	0.015	0.014
	dry basis	0.015	0.014

5 DISCUSSION

The chemical analysis (Table 1) of the Mofia quarry limestone indicates that the composition of the quarry limestone is in fact limestone ($CaCO_3$) with magnesium ions occasionally substituting for calcium (average ratio of Ca: Mg is 14 : 1). The silica content is an indication of the presence of sand and chert deposits in the limestone. Based on the chemical analysis carbonate, calcium, magnesium, silica and organic carbon can be expected to dissolve from the interaction of the limestone with atmospheric carbonic acid (formed from the dissolution of carbon dioxide in rainwater). Chemical equilibrium reactions will dictate the dissolved ion concentrations. Trace metals contained in the quarry limestone was not quantified hence the potential leaching of trace metals could be evaluated.

Water quality at the quarry site (spring water sample) was similar to other groundwater sites. Dissolved oxygen was the lowest for the quarry sample and total dissolved solids, dissolved organic carbon and total suspended solids were higher at the quarry site than at the other groundwater sites. The dissolved organic carbon content is high and is likely attributed to vehicle emissions (from the road close to the sample point) and or agricultural activities. The increased suspended solids in the water sample (488 mg/l) indicate the contribution of natural soil runoff to the water quality at the sample point.

Chemical analysis of the sediment sample indicated a paste pH of 6.6. The total nitrogen was found to be 1.16 percent and was higher than other sediment samples collected on the concession (Physical Baseline Report – Section B2.12). The 20 percent distilled water extract indicated a pH of 7.3 and low dissolved concentrations of metals and non metal species in the extract. A mild nitric acid digestion indicated that 1.38 percent iron, 1.06 percent aluminum and 0.023 percent manganese could be mobilized from the material under mildly acidic conditions. It is unlikely that such conditions arise naturally although the concentration of dissolved ions is dependent on chemical equilibrium reactions.

From the above observations it is unlikely that significant water quality impacts is likely to occur from limestone quarry activities. It is likely that pH, alkalinity, and the concentration of the following elements; calcium, magnesium, silica and organic carbon will increase in the ground and spring water due to the exposure of limestone to precipitation and weathering reactions. Runoff from the waste rock is likely to be largely contained in the quarry but may spill towards the north if flooding occurs hence impacting on the water quality of the quarry sample point. However it is unlikely that water quality changes in the spring or groundwater will be significant due to the presence of natural geochemical

processes and mineral solubility constraints that will determine the quality of seepage and run-off.

The water quality from the spring was found to be good and compliant with US EPA and WHO drinking water quality guidelines (Table A2.7-9). The water was found to be not elevated in organic or inorganic constituents, however a high concentration of E. coli was found probably due to animal feces and or inadequate local sanitation conditions. The water is hard due to the high background cation concentrations which are expected from the local limestone exposures.

The quarry sediment sample was found to be below the probable and threshold effects level for metals (US National Oceanographic and Atmospheric Associations sediment criteria - Table A2.7-10). All organic constituents for the quarry sediment sample were quantified as below detection limit (<50 milligrams per kilogram) and were found to be several times less than the probable effects level or below the threshold effects level except for phenantherene and benzo(a)anthrecene which could not be compared due to the limit of detection of the soluble phase.

6 CONCLUSIONS

The following conclusions can be made from the limestone quarry assessment:

- Exposure of the limestone through quarry activities will have an affect on the quality of water migrating through or running off the exposed limestone materials.
- These affects relate to changes in the chemical nature of the water and the physical properties of the water. The changes in the chemical nature of the water relates to the dissolution of carbonate, calcium and magnesium from the limestone as a result of interaction with carbonic acid in rainwater. The changes in the physical properties of the water relates to increases in the suspended solid loads due to the presence of fine material created during the operation of the quarry.
- It is unlikely that water quality changes will be significant due to the presence of current natural geochemical processes and mineral solubility constraints that will determine the quality of seepage and run-off.
- If storm water were to be discharged from the quarry, it should go through a silt trap system prior to discharge to prevent the transport of sediments to drainage systems. The quality of this water needs to be monitored on regular basis to confirm water quality changes.

APPENDIX B2.4-1

SOIL BASELINE STUDY PHOTOGRAPHS

Photograph 1 Dominant Soil in Soil Map Unit 1

Photograph 2 Peanut Field in Soil Map Unit 1

Photograph 3 Deeply Weathered Red Soil in Soil Unit 2

Photograph 4 Corn Field on Soil Unit 2

Photograph 5 **Soil in Soil Unit 3 – Note Ah Horizon to 17 cm and Cr Horizon at 130 cm**

Photograph 6 **Agricultural Field in Soil Unit 3**

Photograph 7 **Agricultural Field, Remnant Woodland and Charcoal Production in Soil Unit 3**

Photograph 8 **Imperfectly Drained Soil – Soil Unit 4**

Photograph 9 Agricultural Land in Soil Unit 4

Photograph 10 Riverine Gallery Forest in Soil Unit 4

Photograph 11 Shallow Soil – Soil Unit 5

Photograph 12 Landscape – Soil Unit 5

Photograph 13 Agricultural Land/Woodland – Soil Unit 5

Photograph 14 Corn and Cassava Fields – Soil Unit 5

Photograph 15 Thin Soil on Goma Hill - Soil Unit 6

Photograph 16 **Weathered Soil – Kwatebala Hill - Soil Unit 6 - Note High Coarse Fragment Content in Soil Mantle**

Photograph 17 **Thin Weathered Soil with Developed Ah Horizon – Kavifwafwalu (Fwaulu) Hill - Soil Unit 6**

Photograph 18 **Copper Rich Floral Community – Kwatebala Hill - Soil Unit 6**

Photograph 19 Copper Rich Floral Community – Fwaulu Hill - Soil Unit 6

Photograph 20 Town of Tenke – Example of Soil Unit 7

APPENDIX B2.4-II

FIELD SOIL PROFILE DESCRIPTIONS

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-001 **GPS Co-Ordinates:** 35L 0404912
: 8827664

LANDFORM: (Upland) Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl. (Ridge) Other_____

DEPTH OF Organic Matter: (Nil) cm

DEPTH TO GW: ~~Nil~~ NOT SEEN cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
Nil			
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C (U) M L D T Level	VR (R) W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-23 degrees 100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A.	0	5	SL	7.5YR 3/3	Nil			FR	≥75%	A:F D:VF	Nil	5S
CB	5	30	SL	7.5YR 4/3	Nil			FR	≥85%	P:F,F F:F	Nil	5S
R.	30	75	/	/								
R_2	75	150	/	/								

f/c/m f/m/c f/d/p

Land Use - Copper Hill - ROAD CUT
- DEP ARTISINAL MINING

Erosion - NOT SEEN

- picture # 10
- CF - amphibole

Lithic
Dystrostept

PM Texture

L

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2002 **GPS Co-Ordinates:** 35L 0404861
: 8827540

LANDFORM: (Upland) Swamp Other Wetland

SURFACE EXPRESSION :

(Level) Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: ~~Nil~~ 1 cm

DEPTH TO GW: ~~Nil~~ NOT SEEN cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
CANOPY COVER: 15%			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C (U) M L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

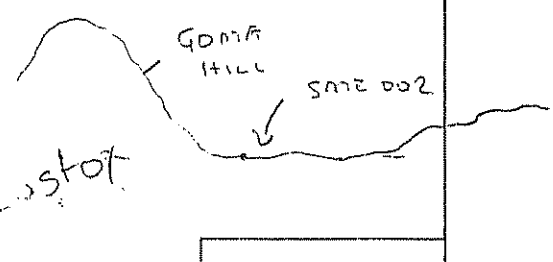
Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	~~Fine~~ Roots	Concretion	pH
A	0	11	SL	7.5YR 3/2	NIL		–	FR	<5%	D;M F;F	NIL	–
B_0		32	SL-L	7.5YR 4/3	"		Present	FR	NIL	D;M F;F	NIL	–
B_0	32	52	SL-L	5YR 4/3	"		Present	FR	NIL	F;F	NIL	–
BC	52	80	SL	5YR 4.5/4	"		–	FR		F;F	NIL	–
R	80	1.0+										–

f/c/m | f/m/c | f/d/p

Land Use – Degraded OPEN SAVANNA – TREES < 5m.

Erosion – NIL

- Close to catena boundary between BC & R.
- Increase in slope - upper portion of new terrain
- sample upper 3 horizons



PM Texture ~~Sandy~~

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: Smz-003 GPS Co-Ordinates: 35'-54 04702
: 8827483

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: ___Nil___ cm (<1 cm)

DEPTH TO GW: _Nil_____ cm (NOT SEEN)

Tree Spp	*Shrub Spp*	Ground Cover Spp
KAPEPE	MASUCOU	Imperata
NUSAMBA	Salbcogia ??	
Varinari curtisiana		

CANOPY COVER: ~ 0%

Parent Material	Slope Position	Drainage	Slope Class
	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
A	0	15	-	7.5YR 3/2								
B_{hb}	15	35	CL	5YR 4/6					NIL			
B_{1hb}	35	65	CL	5YR 4/6					<1%			
BC	65	110+	CL	5YR 4/6					5%			
					f/c/m	f/m/c	f/d/p					

Land Use - open - savana woodland - degraded

Erosion -

- PICTURE 12 - SITE PICTURE
- Coarse frag - 65 cm to 110+ - Bwe

Humic Inceptisol
HAPLUSTOX

IIfSUCOU

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2004 **GPS Co-Ordinates :** 0405052
: 8827764

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: N.C Nil cm

DEPTH TO GW: NOT SEEN ~~Nil~~ cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
NIL		NOT	NOT
		DONE	DONE

CANOPY COVER: <1%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	(C) (U) M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0 5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag	Fine Roots	Concretion	pH
A	0	4	LS	—				—	>90%	—	—	—
CB	4	10	S	—				—	>90%	—	—	—
R	10+											

f/c/m f/m/c f/d/p

Land Use – OLD MINING CLOSE BY – VEGETATION – FRACTURE COMPLETE TIGHT

Erosion –

- NOT SUITABLE FOR SALVAGE

Lithic Ustorthents

PM Texture ~~Sample~~

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SM2005 **GPS Co-Ordinates:** 0400770 : 8821157

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
NOT		NOT	
RECORDED		RECORDED	
CANOPY COVER: 10 - 15%			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
A	0	17	LS	7.5YR 3/2	NIL	W VF SBK	Present	FR	NIL	P F D/VF	–	5.5
(BP0) B1	17	50	L	7.5YR 3/3	NIL	W VF SBK	Present	FR	NIL	–	–	5.0
B1	50	95	CL	7.5YR 4/4	NIL	–	–	FR	NIL	–	–	
(B4) BC0	93	135+	CL	5YR 4/4	NIL	–	–	FR	NIL	–	–	4.5-5.0

f/c/m f/m/c f/d/p

Land Use - OPEN WOODLAND - DEGRADED SAVANNA - TREES < 5m

Erosion - Sol, sheet & rill erosion

PICTURE 14 -
- near Goma Hill
- SITE 20 metres from old termite mound
- gradual - A to B transition
- DUG TO 40 - AUGER TO 135

THE HAPLUSTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-006 **GPS Co-Ordinates:** 0405826
: 8827156

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu Humm Incl Ridge Other_____

DEPTH OF Organic Matter: <1 cm ~~Nil~~ cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		VEGETATION	PLOT – 4
			VOL 1

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M (L) D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100% 17%

Hor	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag	Fine Roots	Concretion	pH
A	0	5	CL	10YR 2/2	NIL	m.F GR	Present	FR	<1%	P-A, F P: VF	NIL	
Bt1	5	30	CL-SiCL	10YR 4/1	NIL	m.m SBK	Present	F	3%	P-A; M P: F	NIL	
Bt2	30	49	CL-C	7.5YR 4/4	NIL	–	–	F	3%	–	NIL	
BC	49	70	CL	7.5YR 4/6	NIL	–	–	F	5%	–	Present (Red & white)	
C	70	85	CL	5YR 4/4 7.5YR 4/6	NIL	–	–	F-VF	10%	–	—	
Cr	85+		—	-	NIL	—	—			—	—	
					f/c/m	f/m/c	f/d/p					

Land Use Miombo

Erosion – Bt - CF - competent - large gravels
BC - CF - fine weathered
- scattered stones on surface

INCEPTIC HAPLUSTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: JMZ007 **GPS Co-Ordinates:** 647528 : 8835220

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: <1cm ~~Nil~~ cm

DEPTH TO GW: NOT SEEN ~~Nil~~ cm

Tree Spp	Shrub Spp	Ground Cover Spp
	NOT	
	RECORDED	
CANOPY COVER:	<15%	

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag	Fine Roots	Concretion	pH
Bo	0	40	SL-L	5YR 3/3	Nil		Prev	FR	<5%	F,VF Fm	–	–
Cr	40	90	SL	2.5YR 3/4	Nil			F	>60	FC Fm	–	–

f/c/m f/m/c f/d/p

Land Use WOODLAND NEAR Coppin Creek Hi

Erosion – NIL

- CF in weathered Saprolite – fine – non cohesive
- gradual Bo – Cr horizon

Tentative HAPLUSTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SM2 008 **GPS Co-Ordinates :** 0407999 : 8830403

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: <1cm ~~Nil~~ cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp	*Shrub Spp*	Ground Cover Spp
	NOT RR	
M. ASOLCO.		

CANOPY COVER: 40%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A	0	20	SL	7.5YR 2/3	–	v.c SBK	–	FR	NIL	A-Vj F A-Pjm	–	SD
B_{t0}	20	75	L-CL	5YR 3/4	–	v.c SBK	–	FR	NIL	Pj F Pjm	–	SD
B_{t0}	75	130	CL	2.5Y 4/6	–	–	–	FR	NIL	–	–	
BC_0	130	152	CL-C	2.5Y 3/6	–	–	–	FR	NIL	–	–	SD

f/c/m f/m/c f/d/p

Land Use MOMBO WOODLAND

Erosion – NIL

- gradual - diffuse boundary - A-B horizon
- dug to 75 - Auger to 152

Humic
Rhodic
Kandistox

PM Texture

- MUTI -
- ARBE -

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-009 GPS Co-Ordinates: 0407447
: 8830280

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm Incl. Ridge Other_____

DEPTH OF Organic Matter: <0.5cm ~~Nil~~ cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		UP-002	

CANOPY COVER: 0%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ah	0	21	L	10YR 2/1	–		–	FR	NIL	A,F	NIL	
Bw	21	37	L	10YR 4/3	–		–	FR	10%	F,F	NIL	
R	37+											

f/c/m f/m/c f/d/p

Land Use – Grassland - Copper Hill

Erosion – NIL

Rock - almost looks granitic

Picture 25 & 26

HUMIC LITHIC Dystrustepts

KAFAFAULO

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2010 **GPS Co-Ordinates :** 0411530
: 8830382

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu Hummock Incl Ridge Other_____

DEPTH OF Organic Matter: ~~Nil~~ NIL cm

DEPTH TO GW: Nil NOT SEEN cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
	NOT		
		DONR	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
COLLUVIAL	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag	Fine Roots	Concretion	pH
C	0	8	SL		—	—	—	—	>70%	—	—	—
Bb	8	44	SC-C	5YR 4/4	—	—		—	15%	—	—	—
CB	44	70	SL-C	7.5YR 4/4	—	—	—	—	15%	—	—	
Cr	70	100		—	—	—	—	—	—	—	—	

f/c/m f/m/c f/d/p

Land Use OLD MINING

Erosion – C- 0 8 - angular complement samples from above 8'
- depth to Cr variable 50cm to 80cm

Picture 28 - soil profile
29 - view to EAST

Lithic Dystrustept

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2 011 **GPS Co-Ordinates :** D410446 : 8830087

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: <0.5 Nil cm

DEPTH TO GW: Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		NOT RECORDED	

CANOPY COVER: < 10%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A	0	4	L	7.5YR 3/3	NIL		Present	FR	NIL	P-F	NIL	—
B-0	4	38	L	7.5YR 4/6	"		Present	FR	NIL	P-F F-C	"	—
BC	38	80	L-SCL	5YR 4/4	"		—	FR-F	35%	"	"	—
Cr	80	130	SL	2.5Y 3/3	"		—		>80%	—	"	—

f/c/m f/m/c f/d/p

Land Use

Erosion –

- open woodland at edge of Kwakbela hill
BC - CF fine - non competent

Dull Dystrophic

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-012 **GPS Co-Ordinates:** 0410362
: 8836367

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Hummm. Incl. Ridge Other_____

DEPTH OF Organic Matter: <0.5cm Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp	*Shrub Spp*	Ground Cover Spp
	NOT	
	RECORDED	
CANOPY COVER:		

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C (U) M L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag	Fine Roots	Concretion	pH
A	0	8	SC	5YR 3/3	NIL	—	Present	FR	NIL	P; F	NIL	
B_1	8	60	SL	5YR 4/4	"	VW.F SBK	"	FR	NIL	P-F; F-P; C	"	
B_2	62	110	SL	5YR 4/4	"	—	"	FR	NIL	VF; F	"	
BC	110	190	L-SC	—	"	—	NIL	FR	NIL	NIL	"	

f/c/m f/m/c f/d/p

Land Use

Erosion –

- deep gully

Typic HAPLUSTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM20:3 **GPS Co-Ordinates :** 0410608
: 3300637

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level: Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: (Nil) cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		CORN	
		FIELD	

CANOPY COVER: NIL

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L B T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
A_p	0	28	L	7.5YR 3/2	NIL	VW vf SB	NIL	FR	NIL	P/F Fm	NIL	
B_p	28	58	L	5YR 4/4	NIL	—	NIL	FR	"	/	"	
B_D	58	80	L	2.5YR 3/6	NIL	—	NIL	FR	"	/	"	
BC	80	110	-CL	2.5YR 3/6	NIL	—	NIL	FR-F	"	/	"	

f/c/m f/m/c f/d/p

Land Use - CORN FIELD

Erosion - some sheet erosion - Redepositing in field.

- PICTURE - CORN FIELD
- Newly cleared Miombo - 25m

- DUG TO 35 - AUGER TO 110

HUMIC FERRIC HAPLUSTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2014 **GPS Co-Ordinates :** 0410893
: 8783083

LANDFORM Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: 0.2 Nil cm

NOT SEEN

DEPTH TO GW: Nil cm

Tree Spp		*Shrub Spp*	**Ground Cover Spp**
	NOT		
		RECORDED	

CANOPY COVER: 40%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M T D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Bo	0	60	L	5YR 4/4	NIL	M-W, M-FSBK	Present	FR	NIL	P-F, D	NIL	
BO	60	135	CL	2.5YR 3/6	NIL		—	FR-F	NIL	—	—	—
BC	135	155	CL-C	2.5Y 3/2	"			F-FR	NIL	—	—	—

f/c/m f/m/c f/d/p

Land Use - Degraded Miombo WOODLANDS - Trees - 8-10m

Erosion – NIL

Ritondic
HAPLUSTOX

PM Texture ~~Sandy~~

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SMZ-01S GPS Co-Ordinates : 04 0177
: 0831307

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl Ridge Other

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp	Shrub Spp	Ground Cover Spp
SGMC	UDOO8	

CANOPY COVER: ~2%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH	
Ap	0	19	LSL	7.5YR 3/3	NIL	–	NIL	FR	NIL	N/D	NIL	/	
B_{hf}	19	55	LCL	5YR 4/4	NIL	–	NIL	FR	NIL	N/D	NIL	/	-Samp
B_{hm}	55	110	CL	5YR 4/6	NIL	–	NIL	FR-F	NIL	N/D	NIL	–	-Samp'

f/c/m f/m/c f/d/p

Land Use CORN FIELD

Erosion –

Humic Rhodic HAPLUSTOX

PM Texture

Meeindgee – corn.

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SMZ-016 **GPS Co-Ordinates:** 0410003 : 8831628

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	**Ground Cover Spp**
		Beans	
		Field	

CANOPY COVER: < 5%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L B T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A_p	0	18	CL	10YR 4/3	NIL	–	–	FR	NIL	N/D	NIL	–
B_o	18	47	CL	10YR 4/2	"	–	–	FR-F	NIL	N/D	NIL	–
BC	47	80	CL	7.5YR 4/2	"	–	–	FR-F	10%	"	"	–
C_F	80	100	C-SiC	5YR 4/3	"	–	–	F-VF	30%	"	"	–
				7.5YR 3/4	"	–	–					
					f/c/m	f/m/c	f/d/p					

Land Use – field of green beans

Erosion – sheet erosion – pedicles...

BC – CF – fine – non competent

HUMIC INCEPTIC
EUTROSTOX
TO HUMIC INCEPTIC
HAPLOSTOX

PM Texture ~~Lacustr~~

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-017 **GPS Co-Ordinates :** 0409464
: 8831408

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu Humm Incl Ridge Other_____

DEPTH OF Organic Matter: 1 cm ~~Nil~~ cm

DEPTH TO GW: NOT SEE ~~Nil~~ cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		NOT	
		RECORDED	
CANOPY COVER: 30%			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A	0	4	L	7.5YR 3/2	NIL		Present	FR	NIL	A; F A; VF	NIL	
B_C	4	45	L	5YR 4/1	NIL	W-m F SBK	Present	FR	NIL	A; m A; F	NIL	
B_D	45	75	CL-L	5YR 4/3	NIL	—		FRF	NIL	—	—	
BC	75	110	CL-SCL	5YR 4/3	NIL	—		F	5%	—	—	
C	110	130		2.5YR 7/6	NIL			F	15%			

f/c/m f/m/c f/d/p

Land Use - cleared Mimbo - at edge of corn field

Erosion – NIL

BC – fine to very fine.

HADLOSTOT

PM Texture

-Wa Packu - omerci
$1.00 = 500 cf

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2 - D13 **GPS Co-Ordinates :** 0409189
: 8831280

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: NIL Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		Corn Field	
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U (M) L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	9	SL-L	7.5YR 3/3	NIL	WVF GR	NIL	FR	NIL	–	NIL	–
Bm	9	45	L-CL	2.5YR 3/4	NIL	–	NIL	FR	NIL	–	NIL	–
(BC) Bjo	45	80	CL	2.5YR 3/6	NIL	–		FR-F	NIL	–	NIL	–

f/c/m f/m/c f/d/p

Land Use Corn field

Erosion – sheet erosion – 1cm pedestaling

– soil different than last site with no apparent change in drainage or topography.

Humic Ortonic Karbistat

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SMZ-019 **GPS Co-Ordinates:** 0409076 : 8831269

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: <0.5cm Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	**Ground Cover Spp**

CANOPY COVER: 20%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A	0	9	SL	7.5YR 3/3	NIL	—	—	FR	NIL	N/D	NIL	
B_D	9	30	L-SL	7.5YR 4/4	NIL	—	—	FR	NIL	"	NIL	
B_G	30	80	CL	2.5YR 3/6	NIL	—	—	FR-F	NIL	"	NIL	

f/c/m f/m/c f/d/p

Land Use – Degraded Miombo

Erosion – NIL

– Drainage – W to MW

HUMIC RHODIC HAPLUSTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-020 **GPS Co-Ordinates:** 0408647
: 8831125

LANDFORM: (Upland) Swamp Other Wetland

SURFACE EXPRESSION:

Level (Undu) Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: 0.5 cm ~~Nil~~ cm

DEPTH TO GW: Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		VDOH	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
Saprolite	C U M (L) D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion ~~Coarse frag~~	pH
A	0	5	SCL	10YR 2/2	NIL	–	Present	FR	NIL	PF	NIL	
Bm	5	15	L-SCL	10YR 3.5/3	NIL	–	Present	FR	NIL	PF	few small	
Bm	15	45	L	7.5YR 4/6	NIL	–	–	M-VH	~~NIL~~	F-F	weak cement	
BB	45	60	L	7.5YR 4/4	NI	–	–	F	45-60 ~~NIL~~	NIL		

f/c/m f/m/c f/d/p

Land Use

Erosion –

- inside coarse frag - 10YR 3/3 & 10YR 7/6 - nodule & striations
- coarse frag at 15-45 - 10R 5/2 - 6-10 cm - weakly cemented - approx - 60%
- topography - no evidence of water table inundation
- coarse frag at 45-60 - 40% - same color - generally smaller diam
- only dug to 60 cm

Typic Kandistoff

PM Texture ~~Texture~~

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2 021 GPS Co-Ordinates: 0108749
: 8831089

LANDFORM: (Upland) Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: 1cm ~~Nil~~ cm

DEPTH TO GW: NOT SEEN ~~Nil~~ cm

Tree Spp		Shrub Spp	Ground Cover Spp
		NOT RECORDED	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W (MW) I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH	
A	0	21	L	7.5YR 3/2	NIL	WF SBK	NIL	FR	NIL	P.M AF	NIL	–	-sample
B1	21	49	L-CL	5YR 3/4	NIL	WF SBK	NIL	FR	NIL	F-P.M F	NIL	–	sample
B2	49	76	CL	2.5YR 3/6	NIL	/	/	FR-F	NIL	–	–	–	
C	76	135	CL-C	2.5YR 3/3	NIL	–	–	F	5%				
					f/c/m	f/m/c	f/d/p						

Land Use degraded miombo – understory cleared for garden

Erosion – not seen

– coarse frag in :– fine – non competent

Humic Rhodic Eutrustoxic to Humic Inceptic Eutrustox

– DUG TO 50cm – Auger to 135

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-022 **GPS Co-Ordinates:** 0410624 : 8831648

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

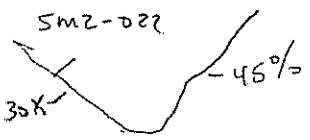
Tree Spp		*Shrub Spp*	Ground Cover Spp
		NOT RECORDED.	
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0 5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag	Fine Roots	Concretion	pH	
Ap	0	9	L	7.5YR 3/2	NIL	WVF SBK	—	FR	NIL	P/F	NIL		-sample
Bm ~~Bt1~~	9	30	L-CL	7.5YR 3/4	NIL	M.F SBK	NIL	FR	NIL	F/F	NIL		-sample
Bw ~~Bt2~~	30	42	CL	7.5YR 3/4	NIL	—	—	FR	NIL	NIL	NIL		
R	42+	—	—	—	—	—	—	—	—	—	—		
					f/c/m	f/m/c	f/d/p						

Land Use – fallow field with scattered trees present

Erosion – present



Humic Lithic Dystrustept

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SMZ-023 GPS Co-Ordinates: 0408461
8829621

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: <05 Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		Shrub Spp	Ground Cover Spp
		NOT	
		RECORDED	

CANOPY COVER: 40%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag	Fine Roots	Concretion	pH
A	0	31	L	7.5YR 3/3	NIL	WBF SOIL	Preeth	FR	NIL	73M Pat, F	NIL	—
Bm	31	65	CL	2.5Y 3/1	NIL	—	—	FR	NIL	—	—	—
Br	65	93	CL SiCL	2.5Y 3/3	NIL	—	—	FR-C	NIL	—	—	—
Cr	93	15	—	10YR 5/4	NIL			E	NIL	—	—	—

f/c/m f/m/c f/d/p

Land Use MIOMBO WOODLAND

Erosion – some erosional deposition on ephemeral creek

SMZ-023

HUMIC RHODIC FERRUSTOX

PM Texture

SIGNED KALALA

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334)

SITE #: SMZ-024 GPS Co-Ordinates: 0408399
: 0859051

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl. Ridge Other:

DEPTH OF Organic Matter: <0.5cm Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		Shrub Spp	Ground Cover Spp.
		Same as	
		above	

CANOPY COVER: 90%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U (M) L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A	0	5	L	7.5YR2	NIL	W VF-F SBK	Prevalent	FR	NIL	F	NIL	—
B_{01}	5	35	L	7.5YR4	NIL	W VF-F SBK	Prevalent	FR	NIL	F	NIL	—
B_{02}	35	66	L	2.5YR4	NIL	—	—	FR-F	NIL	—	—	—
C	66	80	CL-C	10YR5/4	NIL	—	—	F	5%	—	—	

f/c/m f/m/c f/d/p

Land Use Miombo WOODLAND

Erosion – NIL

C – Coarse frag are 5% – fine – non competent

Incipient APPLESTOX

PM Texture

SOIL SURVEY DATA SHEET – Thelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-025 GPS Co-Ordinates: _____

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		Shrub Spp	Ground Cover Spp
		CORN	
		FIEL	

CANOPY COVER: NIL

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D I Level	VR R W MW I P VP	(1) 0-0.5% (2) 0 5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A	0	6	SL	5YR 3/2	NIL	—	—	FR	NIL	—	NIL	—
B0	6	42	SL	5YR 4/4	"	—	—	FR	"	—	"	—
B0	42	79	L	2.5YR 3/6	"	—	—	—	"	—	"	—
BC	79	99	L	2.5YR 3/6	"	—	—	F-FD	80%	—	"	—

f/c/m f/m/c f/d/p

Land Use CORN FIELD

Erosion – SHEET EROSION

RHODIC HAPLUSTOX

PM Texture

Thutle

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SM7-026 **GPS Co-Ordinates:** 0408.22 / 6830234

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm Incl Ridge Other_____

DEPTH OF Organic Matter: <0.5cm Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		NOT RECORDED	
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M I. D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A	0	6	SC	7.5YR 3/2	NIL	—	✓	FR	NIL	—	—	—
B_{O_1}	6	36	CL	5YR 3/4	NIL	—	—	FR	NIL	—	—	—
B_{O_2}	36	88	CL	2.5YR 3/3	NIL	—	—	FR	NIL	—	—	—
BC		88	CL	2.5YR 3/3	NIL	—	—	FR-F	NIL	—	—	—
					f/c/m	f/m/c	f/d/p					

Land Use DEGRADED MOMBS

Erosion – NIL

HUMIC INCEPTIC FERRUDSTOX HUMIC INCEPTIC HAPLUDSTOX

PM Texture		
	HUMIC	

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SM2-027 GPS Co-Ordinates: 041443 / 883134

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu Humm Incl Ridge Other

DEPTH OF Organic Matter: Nil 0.5 cm

DEPTH TO GW: Nil cm NOT SEEN

Tree Spp		Shrub Spp	Ground Cover Spp
		VDOLS	

CANOPY COVER: 00 %

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor	Depth (cm) Top	Depth (cm) Bott	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag	Fine Roots	Concretion	pH
A	0	11	–	5YR 2/1	NIL	m	Prest	FR-VFI	NIL	C C A m	NIL	–
Bm	11	65	CL	2.5YR 3/4	NIL	m F-m SBK	Present	FR	NIL	P m B F	NIL	–
B	65	96	CL	2.5YR 3/5	NIL	–	–	FR-F	NIL	–	–	
C	96	114	–	2.5YR 3/6	NIL	–	–	F	5-10%	–	–	–

f/c/m f/m/o f/d/p

Land Use Degraded

Erosion –

- plant site - possible
- sample 0-11
  11-35
- CF - fine - non competent

HUMIC INCEPTIC HAPLUSTOX
HUMIC INCEPTIC FERRUSTOX

PM Texture ~~Sandy~~

SABLE

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-028 GPS Co-Ordinates: 0411599
: BB31057

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		Agriculture	

CANOPY COVER: NIL

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	16	L	7.5YR 3/3	NIL	MVF SBK	Preen	FR-VFR	NIL	F;F	NIL	
Bm	16	31	L-SiL	7.5YR 3.5/3	F;F,FP	W-MVF SBK	NIL	FR	NIL	F;F	NIL	
C	31	66	SiL	10YR 5/3	—	—	—	—	NIL	NIL	NIL	

f/c/m f/m/c f/d/p

Land Use – field of beans

Erosion – weakly consolidated

Humic
Karndstony

PM Texture

1200 AD

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM7-029 **GPS Co-Ordinates :** 0411524
: 8831006

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		CONIFER	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	18	L	7.5YR 3/2		—	—	FR	—	—	—	—
Bm	18	32	L-SL	7.5YR 3/4		—	—	FR	<1%	—	—	—
BC ~~Bm~~	32	67	L-SL	2.5Y 4/3		—	—		>5%	—	"cream"	—
C	67	80		10YR 4/3		—	—		>5%	—	—	

f/c/m f/m/c f/d/p

Land Use CONIFER

Erosion – Sheet

-B- small frag of CF or concretions
32-67 - coarse frag - small - 1cm diameter

HUMIC INCEPTIC FUTRISTOX

HUMIC FUTRISTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SM2-030 **GPS Co-Ordinates:** 421401 / 8833211

LANDFORM: (Upland) Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu Humm. Incl. (Ridge) Other _____

DEPTH OF Organic Matter: <0.5cm Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		NOT RECORDED	

CANOPY COVER: 45%

Parent Material	Slope Position	Drainage	Slope Class
ANTHROPEGEN	(C) U M L D T Level	VR (R) W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100% SEE DIAGRAM

Hor	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag	Fine Roots	Concretion	pH
C	0	25	SL	10YR 4/3	NIL	—	NOT SEEN	=	>70%		NIL	

f/c/m f/m/c f/d/p

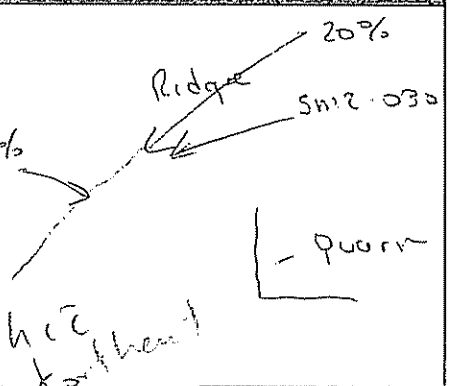
Land Use OLD - Revegetated Quarry site

Erosion – previously disturbed

→ NON Present

- coarse frag - angular, competent

- site revegetated with Acacia pulchella



PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-031 **GPS Co-Ordinates :** 0421267
: 8835325

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: (Nil) cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		NOT RECORDED	
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
ANTHROPEGENIC	C (U) M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) (9-15%) (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
C	0	30	SL	15YR 4/6	NIL	NIL		FR-F	>80%	–	NIL	
					f/c/m	f/m/c	f/d/p					

Land Use WOODLAND - Appears to be revegetated.

Erosion –

- disturbed site - but revegetated with Acacia and Ficus
- poor GPS coverage.
- large cobbles & boulders on surface

Lithic Usteutents

PM Texture

pempouru - birds

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-032 **GPS Co-Ordinates :** 121234
: 8835284

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu Humm Incl. Ridge Other_____

DEPTH OF Organic Matter: ___Nil_____cm

DEPTH TO GW: NOT SEEN _Nil_____ cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		PLOT	
		VD 517	
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
ANTHROGENIC	CT U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag	Fine Roots	Concretion	pH
C	0	20	SL	7.5YR 4/4	NIL	—	—	FR	>80%	—	—	—

f/c/m f/m/c f/d/p

Land Use

Erosion –

Lithic Ustorthents

PM Texture ~~Sandy~~

SOIL SURVEY DATA SHEET -- Phelep Dodge Lenke Project – Soil Survey
(05-1334-035)

SITE #: SMZ-033 GPS Co-Ordinates: 421225
8855250

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu Humm. Incl. Ridge Other

DEPTH OF Organic Matter: ~~Nil~~ 0 cm

DEPTH TO GW: Nil cm NOT SEEN

Tree Spp		Shrub Spp	Ground Cover Spp
		NOT RECORDED	

CANOPY COVER: 60%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITIC	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag	Fine Roots	Concretion	pH
A	0	12	L	1 5YR 2.5/1	NIL	VVF SBK	Present	FR	NIL	A; F	NIL	—
B60	12	49	CL	5YR 3/3	NIL	VVF SBK	Present	FR	NIL	D; F P; m	NIL	—
BC	49	55	CL-L	2.5YR 3/4	NIL	—	—	F FR	5%	—	—	—
Cr	55	63	S	2.5YR 3/4	NIL	—	—	F	>15%	—	—	—
					f/c/m	f/m/c	f/d/p					

Land Use: WOODLAND

Erosion – NIL

BC - CF - fine - non competent could not auger

— Humic Karnolsol

PM Texture

Ecritoura

SOIL SURVEY DATA-SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-034 **GPS Co-Ordinates:** 3429340
: 8026600

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: ___Nil_____cm

DEPTH TO GW: _Nil_____ cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		VD	
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag	Fine Roots	Concretion	pH
B0	0	40	CL	2.5YR3/4	NIL	W.F SBK	Present	FR	NIL	P'jF	NIL	4.5-5.0-Samp
BD	40	76	CL	2.5YR3/4	NIL	W.F SBK	—	FR	<10%	—	NIL	✓
BC	76	89				—		F	5%	✓	NIL	4.5-5.0

f/c/m f/m/c f/d/p

Land Use Fallow Bush land

Erosion – NOT SEEN – EVIDENCE OF OLD SOIL DISTURBANCE – MOUNDING

RHODIC HAPLUSTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SM7-035 **GPS Co-Ordinates:** 0429386 : 8826608

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	8	CL	2.5YR 2/2	NIL	–	–	FR	NIL	–	NIL	–
B0	8	58	CL	2.5YR 3/4	NIL	–	–	FR	NIL	–	NIL	–

f/c/m f/m/c f/d/p

Land Use Peanut field

Erosion – Sheet erosion – 1cm

– Dgil

RHONDIC HAPLUSTOLL

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-036 **GPS Co-Ordinates :** 0416681
: 8831675

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		CORN	
		BEAN	

CANOPY COVER: Nil

Parent Material	Slope Position	Drainage	Slope Class
FLUVIAL / COLLUVIUM	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

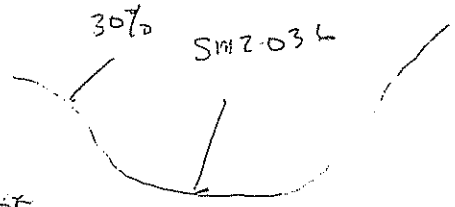
Hor.	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	4	L	7.5YR 3/2	NIL	VW VF SBK	NIL	FR	NIL	F, F	NIL	—
C1	4	10	SL	7.5YR 4/4	NIL	VW VF SBK	NIL	FR	NIL	F, F	NIL	
Ahb	10	25	L	7.5YR 3/2	NIL	W F SBK	NIL	FR	NIL	F, F	NIL	—
Bgh	25	42	L	7.5YR 4/1	NIL	W F SBK	NIL	FR	NIL	F, F	NIL	—
Bgh	42	90	CL	7.5YR 3/1	NIL	—	—	FR	NIL	—	NIL	—
BCgb	90			5YR 6/2	NIL	—	—	FR	<1%	—	—	—
					f/c/m	f/m/c	f/d/p					

Land Use - Agriculture - corn field

Erosion - obvious deposition

C1 - layered

BCb - 1% - fine coarse frag



Humic Eutrustoff

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-037 **GPS Co-Ordinates:** 0411 0676
: 8831728

LANDFORM: (Upland) Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu Humm (Incl.) Ridge Other_____

DEPTH OF Organic Matter: ___Nil____cm

DEPTH TO GW: NOT SEEN _Nil____ cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		MIXED TREE	
		+ CROP LAND	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U (M) L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	9	C	7.5YR 3/2	NIL	—	—	FR	NIL	—	NIL	—
B'	9	48	CL	5YR 4/6	NIL	—	—	FR	NIL	—	NIL	—
B	48	80	CL	5YR 4/6	NIL	—	—	FR-F	NIL	—	NIL	—
BC	80	96	CL SrCL	5YR 4/6	NIL	—	—	F	5%	—	NIL	—
Cr	96	106		2.5YR 4/3	NIL	—	—	F	5%	NIL	NIL	—

f/c/m f/m/c f/d/p

Land Use

Erosion –

Cr – mixed color 2.5YR 4/3, 2.5YR 6/2 – appears not to be mottling but color of ~~rock~~ underlying parent material

Humic Inceptisol
FUTRUSTOX
TO
HUMIC INCEPTISOL
HAPLUSTOX

PM Texture ~~Sandy~~

NG-90-10- continued

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SM2-038 GPS Co-Ordinates: 0410565 : 8831715

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: 0 5cm Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp

CANOPY COVER: 20%

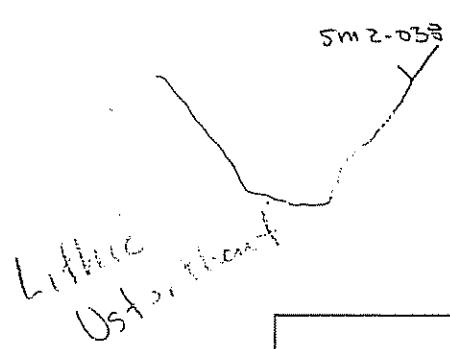
Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
Ah	0	5	L	7.5YR 3/2	NIL		N	FR		O:A;F	NIL	–
BC	8	18	L SL	5YR 3/4	NIL	WM SBK	NIL	FR	3%	F-P;F	NIL	–
Cr	16	30		10R 5/4	–	–	–	–	–	–	–	–
				2.5YR 3/4	–							

f/c/m f/m/c f/d/p

Land Use very degraded

Erosion –



PM Texture

Fourmi - Nga-le-le

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-039 **GPS Co-Ordinates:** 0410305
: 6831724

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		Mamic	
		Field	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	10	L-CL	7.5YR 2.5/1	NIL	W SBK TO FR	NIL	FR	NIL	-	NIL	—
B_{ca}	10	24	L-CL	5YR 3/7	NIL	W F SBK	NIL	FR	NIL	-	"	—
BC_1	24	32	L	7.5YR 4.5/3	NIL	—	—	F	5%	—	"	—
BC_2	32	60	L	10YR 4/2	NIL	—	—	FR-F	1%	—	"	—
C	60	76	L	10YR 5/4	NIL	—	—	F	1%	—	"	—

f/c/m f/m/c f/d/p

Land Use

Erosion –

Ap - variable depth due to mounding for crop production - 10 - 35 cm - 10 bottom mound 35 - top of mound

A

Humic Inceptic Haplustox

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SMZ-010 **GPS Co-Ordinates :** 0411556 : 8832565

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		CORN	
		FIELD	
CANOPY COVER: NIL			

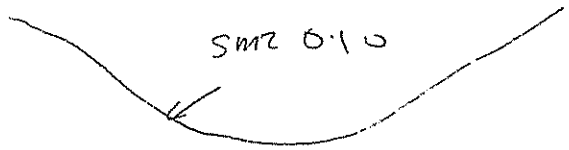
Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH	
Ap	0	10	SL	10YR 3/1	NIL	WF GR	NIL	VFR	5%	P;F P;VR	NIL	–	
CB	10	23	SL	10YR 3/2	NIL	W,M SBK	NIL	FR	35%	–	NIL	–	
C	23	58	SL-L		"	–	"	FR-T	35%	–	NIL	–	
C	58	84	L-CL	7.5YR 3/4	"	–	"	FR T	35%	–	NIL	–	sample
					f/c/m	f/m/c	f/d/p						

Land Use - CORN FIELD

Erosion – Present

CF – medium a fine gravels



PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SM2-041 **GPS Co-Ordinates :** 041502 : 8832490

LANDFORM: ~~Upland~~ Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	**Ground Cover Spp**
		CORN FIELD	
		BEAN FIELD	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	13	C-C	10YR 2/1	NIL	m m-F SBK	Present	FR	NIL	F, F	NIL	—
Bt1	13	42	CC-C	10YR 3/5	NIL	M-F SBK	Present	FR	NIL	F,	NIL	—
Bt2	42	72	C	10YR 3/4	NIL	—	—	F	—	—	NIL	—
BC	72	106	C	10YR 3/4	NIL	—	—	F	—	—	NIL	—

f/c/m f/m/c f/d/p

Land Use

Erosion –

HUMIC XANTHIC KANDIUSTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SMZ-D42 **GPS Co-Ordinates :** 411444 : 8832484

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu Humm Incl Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: Nil cm NOT SEEN

Tree Spp		*Shrub Spp*	Ground Cover Spp
		BEAN	
		FIELD	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH	
Ap	0	28	L-CL	2.5Y 2.5/1	NIL	M UF SBK	NIL	FR	NIL	F,P,F	NIL	—	sampl
AB	28	43	CL	2.5Y 3/1	NIL	M F SBK	NIL	FR	NIL	F,F	NIL	—	c
Bw ~~BE~~	43	76	CL-C	2.5Y 3/1	C.F,F F-D	—	—	F	NIL	—	—	.	sampl
~~BC~~	86	89	CL-CL	2.5Y 3/2	F.F D	—	—	—	—	—			

f/c/m f/m/c f/d/p

Land Use Bean field

Erosion –

- impeded drainage lower point.

Aquic Haplustepts

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-043 **GPS Co-Ordinates :** 111332 : 8832454

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm Incl Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: Nil cm (ABT SERN)

Tree Spp		*Shrub Spp*	Ground Cover Spp
		CORN	
		FIELD	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D I Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	15	L	2.5Y 3/1	NIL	MW VF SB	–	FR	NIL	–	NIL	–
AB	15	29	LCL	2.5Y 3/1	–	–	–	FR	NIL	–	NIL	–
Bo	29	70	CL	2.5Y 3/1	–	–		FR-F	NIL	–	NIL	–

f/c/m f/m/c f/d/p

Land Use – CORN FIELD

Erosion – sheet erosion

Ap – variable depth due to mounding

Humic Ferrihumistox

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM7-044 **GPS Co-Ordinates :** 0429327
: 8826396

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level ~~Undu~~ Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: < 0.5cm Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp	*Shrub Spp*	Ground Cover Spp
	Degraded Savan	

CANOPY COVER: 10 - 15%

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A	0	17	L-SL	7.5YR 3/4	NIL	-	Preson	FR	4%	F,P,F	NIL	
BC1	17	30	SL-L	5YR 4/6	"		NIL	FR	15%	F,F	NIL	—
BC2	30	50	L-CL	5YR 4/6	"			"	30%	—	—	—
Cr	50	62		2.5YR 4/7	"			"	>50%	—	—	—

f/c/m f/m/c f/d/p

Land Use

Erosion –

BC1 - 15% - fine gravels non-competent
30% " " " "

- picture taken of 30 - 50 cm -

PM Texture

Apparentil
Epourantic

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-045 **GPS Co-Ordinates :** 0421519 / 0826546

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		CORN FIELD	
		- MARLOW - FERN	
CANOPY COVER:		<5%	

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH	
A ~~B0~~	0	47	CL	25YR4/4	NIL	SBK	NIL	FR-VFR	NIL	FF	NIL	—	ground sample
~~B0~~	47	124	CL	25YR3/6	NIL	—	—	FR	NIL	—	—	—	

f/c/m f/m/c f/d/p

Land Use

Erosion –

RHODIC HAPLUSTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SML 046 **GPS Co-Ordinates :** 0 129627 : 8826157

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl, Ridge Other_____

DEPTH OF Organic Matter: Nil cm

NOT SEEN

DEPTH TO GW: Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		Recent	
		Field	
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
SHALE/LITH	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	16	L-CL	2.5YR 3/1	NIL	WF SBK	NIL	FR	NIL	–	–	–
Bo	16	84	CL	2.5YR 3/6	NIL		NI	FR-F	NIL	–	–	–

f/c/m f/m/c f/d/p

Land Use – Recent field

Erosion – Sheet Erosion

Ap – variable depth – mounding

Rhodic Haplustox

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Survey
(05-1334-035)

SITE #: SM2-047 GPS Co-Ordinates: 0409594
: 8833468

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl. Ridge Other _____

DEPTH OF Organic Matter: <0.5 Nil cm

DEPTH TO GW: Not Seen Nil cm

Tree Spp		Shrub Spp	Ground Cover Spp
		VD 030	
CANOPY COVER: 70%			

Parent Material	Slope Position	Drainage	Slope Class
SARROLNC	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag	Fine Roots	Concretion	pH
Ah	0	12	L	7.5YR 3/1	NIL	W-M VF SBK	Present	FR	NIL	A F-M P-U	–	
Bhs	12	29	CL	7.5YR 3/6	NIL	M F-M SBK	Present	FR	NIL	P-F F-M	–	
Bhs	29	42	C-CL	5YR 4/6	NIL	W M-F SBK	–	FR	5%	F-F	Present	
BC ~~BCo~~	42	69	C-CL	2.5Y 3/4	NIL	–	–	FI FR	20%	–	–	
C	69	98	CL	2.5YR 4/4 10R 5/4	NIL	–	–	–	30%	–	–	

f/c/m f/m/c f/d/p

– Sample
– omit
sample

Land Use

Erosion –

– CF – fine – non competent 42-66
C – could be Cr

HUMIC
KANDIUSTOL

PM Texture ~~Sample~~

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-048 GPS Co-Ordinates: 0109519
: 8833420

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		Shrub Spp	Ground Cover Spp
		NOT Recorded	

CANOPY COVER: NIL

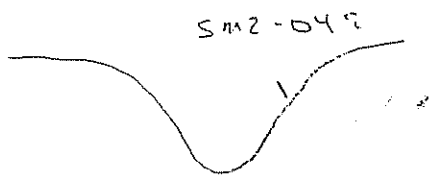
Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag	Fine Roots	Concretion	pH
Ah	0	22	L	7.5 YR 2/1	NIL	—	—	FR	—	—	—	—
Bm	22	62	CL	7.5YR 3/4	NIL	—	—	FR	—	—	—	—
BC	62	85	CL	—	NIL			FR	—	—	—	—
C	85	9	CL	—	NIL			F-FR	2%	—	—	—

f/c/m f/m/c f/d/p

Land Use - VINES & FORBS

Erosion - NIL - NONE SEEN



PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2-049 GPS Co-Ordinates : 0409409
: 8833360

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		Shrub Spp	Ground Cover Spp
		CORN FIELD	

CANOPY COVER: NIL

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ap1	0	12	L-CL	7.5YR 2.5/2	NIL	m-f SBK	NIL	FR	NIL	P-F	NIL	–
Ap2	12	22	L-CL	7.5YR 2.5/2	NIL	m-w f SBK	NIL	FR	NIL	P-F	NIL	–
B	22	46	CL-SICL	7.5YR 4/6	NIL	M, m-f SBK	NIL	FR	7%	F-F	NIL	–
ICr	46	60	CL	2.5YR 4/6	NIL	—	—	F	>15%	—	—	–
Cr	60				NIL	—	—		>25%	—	—	—

f/c/m f/m/c f/d/p

Land Use

Erosion –

Ap2 – inclusions of B hor

HUMIC INCEPTIC EUTROSTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

1603 PM

SITE #: SM2050 GPS Co-Ordinates : 0410008
: 8831744

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
BRAC	BOEH		Beans
CANOPY COVER: 20 %			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A	0	10	L-CL	5Y 3/2		WVF SBK						
Bo	10	42	CL	5Y 3/3.5		WM SBK						
BC1	42	65	CL-SICL	5Y 3/4					5			
BC2	65	82	CL-SICL						10			
C	82	150	L	2.5Y 4/4								
				10R 2.5/1								
				10R 5/3								
					f/c/m	f/m/c	f/d/p					

Land Use

Erosion –

- coarse frags: fine non-competent
- multiple colours in C horizon

INCEPTIC TO INCEPTIC

EUTROSTOX

HAPLOSTOX

PM Texture

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

Feb 13/06
MZ/DN

SITE #: SMZ051 **GPS Co-Ordinates :** 6410037
: 8831545

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: ___Nil____cm

DEPTH TO GW: _Nil____cm not seen

Tree Spp		*Shrub Spp*	**Ground Cover Spp**
CIUT	PIRI	L	

CANOPY COVER: 6-50%

Parent Material	Slope Position	Drainage	Slope Class
	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A	0	4	L-CL	7.5YR 2/2	NIL			FR	m vf sbk			
B_g	4	12	CL	5Y 3.5/4	"			FR	—			
BC_{o1}	12	45	CL 3.6		"			F	m vc fgk	-	--	--
BC_{o2}	45	60			"			F	—		—	—
Cr	60	150		2.5Y 5/6	"			F	—	—	—	—

f/c/m f/m/c f/d/p

Land Use

Erosion –

BC - large angular block - weathered bedrock
could be CB horizon
- Color of unweathered rock 10YR 5/3

Incept Humic
Eutrustox

PM Texture SAND

Incept Humic
Haplustox

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SMZ 053 **GPS Co-Ordinates:** 0468629
: 8829854

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: Nil NOT SEEN cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		Abandoned	
		Field	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
B_D	0	80	CL	2.5Y 3.3/6	–	–	–	FR	0	–	–	

f/c/m f/m/c f/d/p

Land Use

Erosion – – well to mod. well drained

– Describe from Auger

RHODIC HAPLUSTOX

PM Texture SAND		

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2 054 GPS Co-Ordinates : 0408855
: [illegible]

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: ___Nil____cm

DEPTH TO GW: LOT SRF _Nil____ cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		Poa [illegible]	
		Field	
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C (U) M L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

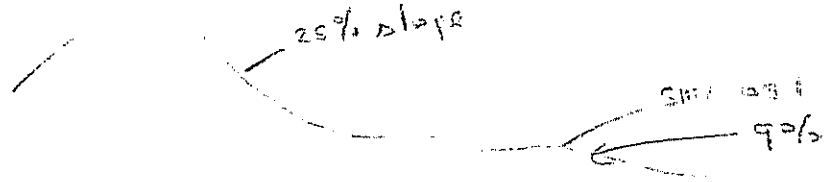
Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
Ho	0	22	L	5YR 3/3	–	–		FR	NIL	–	–	–
BC ~~Bt~~	10	15	SL	–	–	–		FR	Present	–	–	–

f/c/m	f/m/c	f/d/p

Land Use

Erosion –

- unweathered rock – color 10R 5/3



PM Texture SAND		

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

Feb. 4/06

SITE #: SM2055 **GPS Co-Ordinates :** 0410231
: 8831194

LANDFORM: (Upland) Swamp Other Wetland

SURFACE EXPRESSION :

Level (Undu.) Humm. Incl Ridge Other_____

DEPTH OF Organic Matter: (Nil) cm

DEPTH TO GW: (Nil) cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
			CORN FIELD
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U (M) L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
A	0	17	L-CL	7.5YR 2.5/2	N/A	WVF SBK	present	Friable	N/A	plentiful fine	NIL	–
B_{O1}	17	66	C-CL	2.5Y 3/5	N/A	WVF SBK	present	Friable	N/A	plentiful fine	NIL	–
B_{O2}	66	110	CL-SiCL	2.5Y 3/6	N/A	WF SBK	–	Friable	N/A	few fine	NIL	–
BCO	110	150	–	–	N/A	–	–	Friable	N/A	–	NIL	–

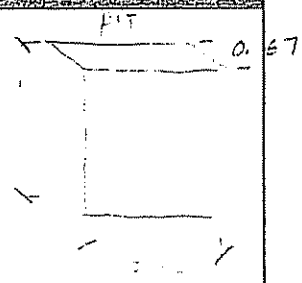
f/c/m f/m/c f/d/p

Land Use

Erosion –

Total depth of pit: 2.9m

Soil appears deeply weathered to 2.9m



Humic RADIC HAPLUSTOX

PM Texture

SOIL SURVEY DATA SHEET – Centralia Westfields (04-1332-028)

SITE #: SM2056 DATE (d/m/y): 4/Feb/06 SURVEYOR(S): M2/DN

NAD: 83 UTM E: 410141 UTM N: 8831357 Aspect: Roll / Photo #:

LANDFORM: (Upland) Bog Fen Swamp Other Wetland

SURFACE EXPRESSION:
Level (Undu) Humm. Incl. Ridge Other

SLOPE 7 %

DEPTH OF O/H Horizon: cm

DEPTH TO GW: cm

Tree Spp		Shrub Spp	Ground Cover Spp
			FALLOW FIELD

CANOPY COVER: (< 6%) 6 - 50% 50 - 100%

ECOSITE: Indicator Species: (If not listed above)

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U (M) L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) >100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Boundary	Text.	Colour	Mottles Abun (<2, 2-20, >20)	Mottles Dim (<5, 5-15, >15)	Mottles Con	Mottles Colour	Structure	Consist D M W	Coarse Frag.	Roots	Pores	Concretions
A	0	14	Grad.	L	5YR 3/3	N	/A	—	—	WVF SBK	FRIABLE	N/A			
Bo1	14	70	Dif.	L	2.5Y 3/5	N	/A	—	—	WF SBK	FRIABLE	N/A			
Bo2	70	115	Dif.	L-CL	2.5Y 3/6	N	/A	—	—	WF SBK	Friable	N/A			
CR	115	200			10Y 5.5/4										
						f/c /m	f/m/c	f/d/p							

COMMENTS: Shaded fields are optional

Samples Taken Yes. No – More roots @ Bo2 / CR interface

Effervescence – CR: [illegible]

Site Index – Age
HT
DBH (OB)
DBH (IB)

[illegible]
HAPLUSTOX

PM Texture	Ecosite	Subgroup	Series

Structure: Single Grain (SG) Granular (GR) Platy (PL) Subangular Blocky (SBK) Angular Blocky (ABK) Prismatic (PR) Massive (M)

Consistence: Loose (L) Very Friable (VFR) Friable (FR) Firm (F) Very Firm (VF)

409818 / 88319 [illegible]
409881 / 88[illegible]-922
409[illegible] / 88[illegible]-916

Golder Associates Ltd.

(4) 41[illegible] E 410122 / 5[illegible]

Phelps-Dodge Tumbler Project

SOIL SURVEY DATA SHEET – ~~Centralia Westfields (04-1332-028)~~

SITE #: SMZ057 **DATE (d/m/y):** 4/Feb/06 **SURVEYOR(S):** MZ/DN

NAD: 83 UTM E: 410018 **UTM N:** 8831857 **Aspect:** **Roll / Photo #:**

LANDFORM: (Upland) Bog Fen Swamp Other Wetland

SURFACE EXPRESSION :
Level (Undu) Humm. Incl. Ridge Other

SLOPE _____%

DEPTH OF O/H Horizon: ____ cm

DEPTH TO GW: ____ cm

Tree Spp	Shrub Spp	Ground Cover Spp
		CORN FIELD

CANOPY COVER: (<6%) 6 - 50% 50 - 100%

ECOSITE: Indicator Species: (If not listed above)

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M (L) D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) >100%

Hor.	Depth (cm) Top	Depth (cm) Bot.	Boundary	Text.	Colour	Mottles <2, 2-20, >20 <5, 5-15, >15 Abun	Dim	Con	Colour	Structure	Consist D M W	Coarse Frag.	Roots	Pores	Concretions
A	0	9		L-CL	5Y 2.5/1		N	"		W VF SBK	FRIABLE	N/A			N/A
BA	9	38		CL-SiCL	5YR 3/3			"		WM VF-F SBK	FRIABLE	N/A			N/A
Bo1	38	60		SiCL-CL	2.5Y 3/4			"		WVF SBK	FRIABLE	N/A			N/A
Bo2	60	100		SiCL-CL	5YR 3/3			"		WM-F SBK	FRIABLE	N/A			N/A
BC	100	160		SiCL-CL	2.5Y 3/5			"			FRIABLE	N/A			
						f/c /m	f/m/c	f/d/p							

COMMENTS: Shaded fields are optional

Samples Taken Yes. No

Effervescence

Site Index – Age
HT
DBH (OB)
DBH (IB)

HUMIC GLEYSOL
FIBRISTOX

PM Texture	Ecosite	Subgroup	Series

Structure: Single Grain (SG) Granular (GR) Platy (PL) Subangular Blocky (SBK) Angular Blocky (ABK) Prismatic (PR) Massive (M)

Consistence: Loose (L) Very Friable (VFR) Friable (FR) Firm (F) Very Firm (VF)

Phelps-Dodge Tenke Project

SOIL SURVEY DATA SHEET – Centralia Westfields (04-1332-028)

SITE #: SMZ058 DATE (d/m/y): 4/Feb/06 SURVEYOR(S): MZ/EN

NAD: 83 UTM E: 410035 UTM N: 8831897 Aspect: Roll / Photo #:

LANDFORM: Upland Bog Fen Swamp Other Wetland

SURFACE EXPRESSION :
Level Undu Humm. Incl. Ridge Other

SLOPE 5 %

DEPTH OF O/H Horizon: cm

DEPTH TO GW: cm

Tree Spp		Shrub Spp	Ground Cover Spp
			Corn field

CANOPY COVER: < 6% 6 - 50% 50 - 100%

ECOSITE: Indicator Species: (If not listed above)

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) >100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Boundary	Text.	Colour	Mottles Abun (<2, 2-20, >20 <5, 5-15, >15)	Mottles Dim	Mottles Con	Mottles Colour	Structure	Consist D M W	Coarse Frag.	Roots	Pores	Concretions
A_1	0	18		L	5Y 3/2	N/A				W/F SBK	Friab -V. Frmb	N/A			
B_{O_1}	18	34		CL	2.5Y 3/5	N/A				WF SBK	Friable	N/A			
B_{O_2}	34	75		CL-SiCL	2.5YR 3/5	N/A				MF SBK	friable	N/A			
BC_1	75	125		SiCL-CL	2.5Y 3.5/6			N/A				15% fine-			
CR_1	125	172		N/A	10YR 6/6 10YR 3/1 (minor)			N/A							
CR_2	172	200		N/A	10YR 6/6 10YR 3/1 (minor)				N/A						
						f/c /m	f/m/c	f/d/p							

COMMENTS: Shaded fields are optional

Samples Taken Yes. No

non-competent coarse fragments in BC horizon

Effervescence

Site Index – Age
HT
DBH (OB)
DBH (IB)

Humic Inceptic Eutrustox to Humic Inceptic Haplustox

PM Texture	Ecosite	Subgroup	Series

Structure: Single Grain (SG) Granular (GR) Platy (PL) Subangular Blocky (SBK) Angular Blocky (ABK) Prismatic (PR) Massive (M)

Consistence: Loose (L) Very Friable (VFR) Friable (FR) Firm (F) Very Firm (VF)

SOIL SURVEY DATA SHEET – Centralia Westfields (04-1332-028)

SITE #: SM2059 DATE (d/m/y): 4/Feb/06 SURVEYOR(S): MZ / DN

NAD: 83 UTM E: 410135 UTM N: 8831895 Aspect: Roll / Photo #:

LANDFORM: (Upland) Bog Fen Swamp Other Wetland

SURFACE EXPRESSION :
Level (Undu.) Humm. Incl. Ridge Other

SLOPE 7 %

DEPTH OF O/H Horizon: cm

DEPTH TO GW: cm

Tree Spp		Shrub Spp	Ground Cover Spp
			CORN Field

CANOPY COVER: (<6%) 6 - 50% 50 - 100%

ECOSITE: Indicator Species: (If not listed above)

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C (U) M L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) >100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Boundary	Text.	Colour	Mottles Abun (<, 2-20, >20 <5, 5-15, >15)	Mottles Dim	Mottles Con	Mottles Colour	Structure	Consist D M W	Coarse Frag.	Roots	Pores	Concretions
Ah	0	17		L	2.5YR 2.5/1					MF SBK	friable	N/A			N/A
Bo	17	59		CL	2.5Y 3/4					W F-VF SBK	↓	N/A			
BC	59	130		CL	[illegible]						↓	10% F-NC			
[illegible]	190	190		N/A	10R 5/4										
[illegible]	190	260		N/A	10R 4/4										
						f/c /m	f/m/c	f/d/p							

COMMENTS: Shaded fields are optional

Samples Taken Yes. No

Effervescence

Site Index – Age
HT
DBH (OB)
DBH (IB)

Hamac Incept [illegible]
Hamac Incept [illegible]

PM Texture	Ecosite	Subgroup	Series

Structure: Single Grain (SG) Granular (GR) Platy (PL) Subangular Blocky (SBK) Angular Blocky (ABK) Prismatic (PR) Massive (M)

Consistence: Loose (L) Very Friable (VFR) Friable (FR) Firm (F) Very Firm (VF)

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: Sm2 060 **GPS Co-Ordinates:** 0416784
: 8826778

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION:

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: ~~Nil~~ 15cm cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		Gallery	
		Forest	
CANOPY COVER: 80%			

Parent Material	Slope Position	Drainage	Slope Class
Fluvial	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
Ah	0	22	SL	10YR 3/2	–	–	–	–	Nil	–	–	–
C	22	38	fSL	10YR 3/2	–	–	–	VFR	–	–	–	–
C	38	65	CL	75YR 3/2	C;F;D	–	–	–	–	–	–	–
C	38	90	C	25Y 3/3	Nil	–	–	–	–	–	–	–
					f/c/m	f/m/c	f/d/p					

Land Use

Erosion – site – gullying forest near Dopefer River
– site beside stream

Aquic Ustifluvents

PM Texture SAND		

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM2 061 **GPS Co-Ordinates:** 10° 34' 09"
: 26° 10' 32.8

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEE- Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		CORN FIELD	
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
A	0	5	L	7.5YR 3/2	–	v vf sbk	–	FR	NIL	A-P;F	NIL	
BA	5	22	L	5Y 3/3	–	v vf sbk	–	FR	NIL	P;F	NIL	
Bo	22	60	CL-SCL	5YR 4/4	–	w vf sbk	–	FR	NIL	F-F F-M	NIL	
BC	60	130	CL	2.5YR 3.5/3	–	w fs blc -crum c		–	20% -FIMR			
Cr	130	160		10YR 5/3	–	–	–	–	weathered rock	–	–	–

f/c/m f/m/c f/d/p

Land Use

Erosion –

PM Texture SAND	Humic Inceptic Fluvisol

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SM7 -062 **GPS Co-Ordinates :** _____
: _____

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		CORN FIELD	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
	C U M L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0 5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	11	L	7.5YR 3/3 7.5YR 3/2	–	WVF SBK CRUMB	–	FR-VFR	NIL	P-F	NIL	–
Bto	11	52	CL	5YR 4/4	–		–	FR-VFR	"	F-F	NIL	–
Bto	52	132	CL	2.5YR 3/4	–	WVF SBK CRUMB	–	FR	"	NIL	NIL	–
C	132	160	CL	2.5YR 3/6	–	–	–	FR	"	NIL	NIL	–

f/c/m f/m/c f/d/p

Land Use

Erosion – – diffuse boundaries between B horizon
– Ap variable depth

PM Texture SAND | Humic Rhodic Ferralsol

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SM2-063 **GPS Co-Ordinates :** _____
: _____

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: ___Nil____cm

DEPTH TO GW: _Nil____ cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		Depauperated	
		Miombo	
		Woodlan	
CANOPY COVER: 35%			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C U (M) L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
Ah	0	12	CL-L	7.5YR 3/2	–	v vfsbk	–	v.fr		B; F P-F; vc	–	–
Bto ~~Bo~~	12	37	CLL	5YR 4/4	–	m vfsbk	–	v fr	20%	P; F P-F; m	–	–
CB	37	85	CL	2.5YR 4/6	–		–	v.fr	5-10%	Nil	–	–
C	88	120	CL	5YR 4/4	–	–	–	–	5-10%	–	–	–
Cr	120	152	–	10YR 4/2	–	Pseudo ABK	–	–	–	–	–	–

f/c/m f/m/c f/d/p

Land Use

Erosion –

coarse from 12-37 - fine - coarse gravels - non compactant

Cr - very well weathered rock

CBa C - high C.F content - non compactant

B - horizon - fine - coarse gravels - no

HUMIC INCEPTIC Haplustoy

PM Texture SAND

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey (05-1334-035)

SITE #: SMZ 064 **GPS Co-Ordinates :** _____
: _____

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: Nil cm NOT SEEN

Tree Spp		*Shrub Spp*	Ground Cover Spp
		CONFIFER	
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
	C (U) M L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag	Fine Roots	Concretion	pH
Ap	0	17	L	7.5YR 2.5/1	–	W VF SBK	–	FR-VFR	NIL	F-M D-F	NIL	–
Bn	17	66	L-CL	2.5YR 3/3	–	W-VF SBK CRUMB	–	FR-VFR	NIL	F-F	NIL	–
Bo	66	150	CL-C	2.5YR 2/3	–	W-VF SBK CRUMB	–	FR VF	NIL		NIL	–

f/c/m f/m/c f/d/p

Land Use

Erosion –

Humic Rhodic Humistox

PM Texture SAND

Humic Rhodic Humistox

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SMZ 065 **GPS Co-Ordinates :** _____
: _____

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: ___Nil___ cm

DEPTH TO GW: _Nil_____ cm

Tree Spp		*Shrub Spp*	**Ground Cover Spp**
		CONIFER	

CANOPY COVER:

Parent Material	Slope Position	Drainage	Slope Class
SHPROLITE	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
Ap	0	22	L-CL	7.5YR 2.5/1	–	U vF SBK	–	FR-VFR	Nil	A;F	–	–
B~~t~~ Bt	22	48	CL-SiCL	5YR 2.5/3.5	–	w-m vF SBK	–	FR	Nil	F;F	–	–
CB	48	55	–	–	–	–	–	–	20%	–	–	
Cr1	55	145	–	2.5YR 2/4 2.5YR 6/2	–	–	–		–		–	–
Cr2	145	175	–	5YR 6.5/3	–	–	–		–		–	–

f/c/m f/m/c f/d/p

Land Use

Erosion –

Cr1 – very soft well weathered rock
Cr2 – weathered rock but more consolidated than Cr1

HUMIC
KANDISTOX

PM Texture SAND

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SMZ 066 **GPS Co-Ordinates :** _____
: _____

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		Agriculture	
CANOPY COVER:			

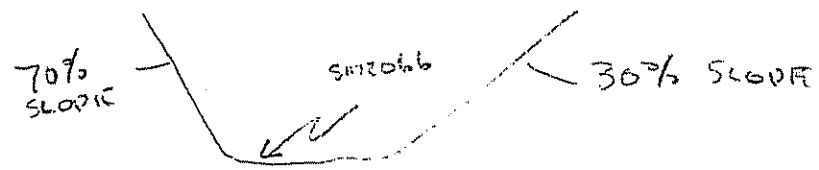
Parent Material	Slope Position	Drainage	Slope Class
	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
A	0	16	L	5YR 3/1S	–	W VF SBK CRUM	–	VFR-FR	NIL	PF	NIL	–
Bo	16	66	L	5YR 3/4	–	W VF SBK CRUMB	–	FR	NIL	P-F;F	NIL	–
Bo	66	140	L	2.5YR 3/4	–	W VF SBK CRUMB	–	FR	NIL	F-VF ROOTS	NIL	–
Bo	140	200	L-CL	2.5YR 3/4	–	–	–	FR	NIL		NIL	–

f/c/m f/m/c f/d/p

Land Use

Erosion – PM – COULD BE WELL WEATHERED SAPROLITE OR FLUVIAL



PM Texture SAND | RH to die Fulvustox

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SMZ 067 **GPS Co-Ordinates :** _____
: _____

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level (Undu.) Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: (Nil) cm
NOT SEEN.

DEPTH TO GW: Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		CORNFIELD	
CANOPY COVER:			

Parent Material	Slope Position	Drainage	Slope Class
SAPROLITE	C (U) M L D T Level	VR R (W) MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) (9-15%) (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Bott.	Text	Colour	Mottles	Structure	Pores	Consist D M W	Coarse Frag.	Fine Roots	Concretion	pH
A	0	10	L-CL	5YR 3/2	–	W VF SBK	–	FR-VFR	NIL	P,F	–	–
B_{t0}	10	42	CL	2.5YR 3/3	–	W-M VF SBK	–	F-VFR	NIL	F,F	–	–
BC	42	70	CL	2.5YR 3/3	–	–	–	–	20%	–	–	–
Cr	70	140		10YR 6.5/6 2.5YR 7/2	–	–	–	–	–	–	–	–

f/c/m f/m/c f/d/p

Land Use

Erosion –

CF in BC horizon

BC - could be CB horizon - fine - medium angular grade

Cr - mix of yellowish & red weathered rock

PM Texture SAND	Inceptic Eutrustox

Inceptic Haplustox

SOIL SURVEY DATA SHEET – Phelep Dodge Tenke Project – Soil Survey
(05-1334-035)

SITE #: SMZ 063 **GPS Co-Ordinates :** _____
: _____

LANDFORM: Upland Swamp Other Wetland

SURFACE EXPRESSION :

Level Undu. Humm. Incl. Ridge Other_____

DEPTH OF Organic Matter: Nil cm

DEPTH TO GW: NOT SEEN Nil cm

Tree Spp		*Shrub Spp*	Ground Cover Spp
		CORNFIELD	
CANOPY COVER: 0 %			

Parent Material	Slope Position	Drainage	Slope Class
SHPBOLTR	C U M L D T Level	VR R W MW I P VP	(1) 0-0.5% (2) 0.5-2% (3) 2-5% (4) 5-9% (5) 9-15% (6) 15-30% (7) 30-45% (8) 45-70% (9) 70-100% (10) <100%

Hor.	Depth (cm) Top	Depth (cm) Bott.	Text	Colour	Mottles	Structure	Pores	Consist DMW	Coarse Frag.	Fine Roots	Concretion	pH
A	0	9	L	7.5YR 2/1	—	w VF SBK CRUMB	—	VFR	—	P,M P-F,F	—	—
B_{ew}	9	57	CL	2.5YR 3/4	—	w VF SBK	—	FR VFR	—	P-F,F	—	—
CB	57	145	CL	2.5YR 3.5/6	—	—	—	—	20%	—	—	—
Cr	145	190	—	2.5YR 7/6	—	—	—	—	—	—	—	—

f/c/m f/m/c f/d/p

Land Use

Erosion –

CF in CB horiz are 10YR 8/1 – coarse frag very well weathered – rounded (can break with hand

PM Texture SAND		

HUMIC FERRIC HAPLOSTOX

APPENDIX B2.4-III

MODAL SOIL PROFILE DESCRIPTIONS

Modal Profile Description - Rhondic Haplustox

Soil Inspection Site SMZ045

Some of the site characteristics are as follows:

Table 1 Site Characteristics

Soil Characteristics	Description
soil classification (USDA)	Rhondic Haplustox
location	two kilometers east of Fungurume
topography (% slope)	2%
slope position	mid
drainage class	well
predominant vegetation type	cornfield

Table 2 Field Soil Profile Description

Site SMZ045					
Horizon	**Depth (cm)**	**Colour**	**Texture**	**Structure**	**Moist Consistence**
A	0-47	2.5YR4/6	CL	-	-
Bo	47-121	2.5YR3.5/6	CL (C)	MMSBK	V.FR - FR

Table 3 Soil Profile Chemical and Physical Characteristics

SITE SMZ045																
Horizon	Depth (cm)	pH (water)	pH (KCl)	CEC cmol /kg	Base Saturation %	Extractable Bases				Exc Acidity cmol/kg	Particle Size			Phosphorus Mg/kg	Organic Carbon %	Total Nitrogen %
						Na cmol/kg	K cmol/kg	Ca cmol/kg	Mg cmol/kg		% clay	% sand	% silt			
A	0-47	5.64		10.449	13.81	0.095	0.233	0.586	0.528	1.120	42	46	13	3.29	0.68	0.044
Bo	47-121	5.80	4.16	7.058	19.66	0.113	0.435	0.459	0.381	0.836	48	35	17	1.92		

Modal Profile Description – Humic Rhondic Haplustox

Soil Inspection Site SMZ055

Table 4 Site Characteristics

Soil Characteristics	Description
soil classification (USDA)	Humic Rhondic Haplustox
location	two kilometers south east of Mulumbu
topography (% slope)	5-9%
slope position	mid
drainage class	well
predominant vegetation type	cornfield

Table 5 Field Soil Profile Description

Site SMZ055					
Horizon	**Depth (cm)**	**Colour**	**Texture**	**Structure**	**Moist Consistence**
A	0-17	7.5YR2.5/2	CL-L	W-M.VF.SBK	V.FR - FR
Bo1	17-66	2.5YR3.3/5	CL -C	M.VF.SBK	V.FR - FR
Bo2	66-110	2.5YR3.3/6	CL-C	W-M.VF.SBK	V.FR - FR
BCo	110-150	2.5YR3.3/5			FR

Table 6 Soil Profile Chemical and Physical Characteristics

Site SMZ055																
Horizon	Depth (cm)	pH (water)	pH (KCl)	CEC cmol/kg	Base Saturation %	Extractable Bases				Exc Acidity cmol/kg	Particle Size			Phosphorus Mg/kg	Organic Carbon %	Total Nitrogen %
						Na cmol/kg	K cmol/kg	Ca cmol/kg	Mg cmol/kg		% clay	% sand	% silt			
A	0-17	6.46		4.763	78.22	0.112	0.305	1.409	1.900	0.165	24	49	26	4.98	1.19	0.060
Bo1	17-66	5.81		11.047	20.78	0.091	0.413	0.585	1.206	0.343	44	33	21	2.63		MMSBK
Bo2	66-110	5.66	4.36	9.580	21.00					0.439	46	32	22	1.92		MFSBK

Modal Profile Description – Humic Rhondic Eutrustoy

Soil Inspection Site SMZ021

Table 7 Site Characteristics

Soil Characteristics	Description
soil classification (USDA)	Humic Rhondic Eutrustox
texture (surface/subsurface)	four kilometers south east of Mulumbu
topography (% slope)	5%
slope position	mid
drainage class	well
predominant vegetation type	cleared Miombo

Table 8 Field Soil Profile Description

Site SMZ021					
Horizon	**Depth (cm)**	**Colour**	**Texture**	**Structure**	**Moist Consistence**
A	0-21	7.5YR2.3/2	CL-L	M.VF.SBK	FR
Bto	21-49	5YR3.3/4	CL-L	M-W.VF.SBK	FR
Bto	49-76	2.5YR3/6	CL		FR
C	0	2.5YR3/3	CL		F

Table 9 Soil Profile Chemical and Physical Characteristics

SITE SMZ021																
Horizon	Depth (cm)	pH (water)	pH (KCl)	CEC cmol/kg	Base Saturation %	Extractable Bases				Exc Acidity cmol/kg	Particle Size			Phosphorus Mg/kg	Organic Carbon %	Total Nitrogen %
						Na cmol/kg	K cmol/kg	Ca cmol/kg	Mg cmol/kg		% clay	% sand	% silt			
A	0-21	6.16		7.244	51	0.112	0.410	1.133	2.062		22	53	25	4.09	1.56	0.076
Bto	21-49	6.04	4.46	6.307	36	0.108	0.296	0.478	1.417	0.364	32	45	22	2.14		

Soil Modal Profile Description – Aquic Eutrustept

Soil Inspection Site SMZ042

Table 10 Site Characteristics

Soil Characteristics	Description
soil classification (USDA)	Aquic Haplustepts
Location	800 metres north west of Mulumbu
topography (% slope)	0.5-2 %
slope position	toe
drainage class	imperfect
predominant vegetation type	bean field

Table 11 Field Soil Profile Description

Site SMZ042						
Horizon	**Depth (cm)**	**Colour**	**Texture**	**Structure**	**Mottles**	**Moist Consistence**
Ap	0-28	2.5Y2.2.5/1	L-SiL	W.VF.SBK		FR
AB	28-43	2.5Y3.3/1	CL	M.VF-F.SBK		FR
Bw	43-76	2.5Y3/6	CL-C		C-F;F;F-D	Firm-Friable
BC	76-89	5YR4/4	CL-C		F;F;D	

Table 12 Soil Profile Chemical and Physical Characteristics

SITE SMZ042																
Horizon	Depth (cm)	pH (water)	pH (KCl)	CEC cmol/kg	Base Saturation %	Extractable Bases				Exc Acidity cmol/kg	Particle Size			Phosphorus Mg/kg	Organic Carbon %	Total Nitrogen %
						Na cmol/kg	K cmol/kg	Ca cmol/kg	Mg cmol/kg		% clay	% sand	% silt			
Ap	0-28	6.70		26.232	93.72	0.149	0.396	14.482	9.559	0.124	28	21	50	10.77	6.22	0.247
AB	28-43	5.98	4.41	12.006	75.76	0.128	1.337	0.741	6.889	0.356	32	37	31	1.43		

Soil Modal Profile Description – Humic Lithic Dystrustept

Soil Inspection Site SMZ022

Table 13 Site Characteristics

Soil Characteristics	Description
soil classification (USDA)	Humic Lithic Dystrudepts
location	1.5 kilometers west of Mulumbu
topography (% slope)	30 %
slope position	mid
drainage class	well
predominant vegetation type	cornfield with slected trees

Table 14 Field Soil Profile Description

Site SMZ022					
Horizon	**Depth (cm)**	**Colour**	**Texture**	**Structure**	**Moist Consistence**
Ap	0-9	7.5YR.3/2	L	W.F.GR	FR
Bw1	9-30	7.5YR3/4	L-CL	M.F.SBK	FR
Bw2	30-42	7.5YR3/1	CL		FR
R	3&+				

Table 15 Soil Profile Chemical and Physical Characteristics

Horizon	Depth (cm)	pH (water)	pH (KCl)	CEC	Base Saturation %	Extractable Bases				Exc Acidity K cmol/kg	Particle Size			Phosphorus mg/kg	Organic Carbon %	Total Nitrogen %
						Na cmol/kg	K cmol/kg	Ca cmol/kg	Mg cmol/kg		% clay	% sand	% silt			
Ap	0-9	6.57		17.237	62	0.141	0.744	4.396	5.460		22	35	43	7.66	2.6	0.163
Bw1	9-30	5.94		13.281	38	0.121	0.571	0.480	3.817	0.604	32	27	41	1.56		

Soil Modal Profile Description – Humic Lithic Dystrustept

Soil Inspection Site SMZ009

Table 16 Site Characteristics

Soil Characteristics	Description
soil classification (USDA)	Humic Lithic Dystrudepts
location	
topography (% slope)	2-5 %
slope position	upper
drainage class	rapid
predominant vegetation type	cornfield

Table 17 Field Soil Profile Description

SITE SMZ009					
Horizon	**Depth (cm)**	**Colour**	**Texture**	**Structure**	**Moist Consistence**
Ah	0-21	10YR.2/1	L-SCL		FR
Bw	21-37	10YR4/3	L-SCL		FR
R	3&+				

Table 18 Soil Profile Chemical and Physical Characteristics

SITE SMZ009																		
Horizon	Depth (cm)	pH (water)	pH (KCl)	CEC cmol/kg	Base Saturation %	Extractable Bases				Exc Acidity K cmol/kg	Particle Size			Phosphorus mg/kg	Organic Carbon %	Total Nitrogen %	Cu mg/kg	Co mg/kg
						Na cmol/kg	K cmol/kg	Ca cmol/kg	Mg cmol/kg		% clay	% sand	% silt					
Ah	0-21	5.94		12.9	53	0.107	0.459	3.633	2.637		24	65	11	4.41	4.96	0.187	2021	295
Bw	21-37	5.7	4.35	5.675	29	0.104	0.141	0.551	0.837	0.828	22	54	24	1.6			1922	800
R	3&+																	

APPENDIX B2.4-IV

SOIL ANALYTICAL PROPERTIES
(1998 AND 2006 SOIL SAMPLES)

Table 1 Analyses of Soil Copper/Cobalt Content, 1998

Soil Pit	Horizon	Horizon (mm)	Total Cu	Total Co	pH
Uapaca wood (miombo-woodland)	1	0 to 30	1,170	165	6.2
	2	30 to 100	1,200	170	4.8
	3	100 to 200	1,280	160	4.5
	4	200 to 300	1,260	unknown	4.8
	5	300 to 550	1,340	unknown	4.5
copper clearing (copper-cobalt steppe-savanna)	1	0 to 10	5,000	640	7.0
	2	10 to 80	5,400	520	5.3
	3	80 to 300	5,200	789	5.0
	4	300 to 440	4,800	595	4.7

Note: Metals expressed as parts per million air-dried soil.

Table 2 Results of Soil Analysis, 1998

Sample Location	pH	V mg/kg	Co mg/kg	Ni mg/kg	Zn mg/kg	Cu mg/kg	As mg/kg	Hg mg/kg	Pb mg/kg	Se mg/kg	Mo mg/kg	Cd mg/kg	Sn mg/kg	Sb mg/kg	Ba mg/kg	Bi mg/kg	F mg/kg
Range in Normal Soils[a,b]	**4.5 to 6.5**	**20 to 500**	**1.0 to 50**	**5 to 500**	**10 to 300**	**5 to 200**	**0.1 to 40**	**<0.001 to 0.5**	**2 to 200**	**0.1 to 2.0**	**0.2 to 5**	**0.01 to 1**	**<1 to 10**	**NAv**	**100 to 4,000**	**NAv**	**30 to 300**
1	5.45	24.17	27.88	6.51	21.02	77.91	2.26	0.07	8.60	ND[c]	0.13	0.15	1.14	0.05	19.47	0.59	420
2	6.56	63.81	26.03	16.02	32.27	36.51	2.91	0.07	12.90	ND	0.08	0.20	1.27	0.05	113.48	0.33	284
3	6.33	65.65	22.20	16.78	38.32	39.44	2.91	0.16	23.33	ND	0.11	0.29	1.41	0.02	151.62	0.31	350
4	7.05	69.23	28.17	17.09	44.10	40.48	3.01	0.12	19.18	ND	0.00	0.19	1.01	0.01	142.14	0.29	406
5	6.32	50.29	21.03	13.02	35.82	37.57	4.31	0.12	11.99	ND	0.34	0.16	1.30	0.03	56.33	0.30	274
6	7.52	58.78	16.01	17.09	51.08	36.53	3.39	0.09	20.43	ND	0.00	0.09	1.11	0.01	83.13	0.19	550
7	7.46	49.07	12.52	12.34	29.13	12.18	0.92	0.09	10.72	ND	0.00	0.16	1.14	0.01	152.90	0.13	272
8	5.66	16.20	2.10	4.06	8.34	11.87	0.00	0.04	7.10	ND	0.00	0.13	1.38	0.02	34.25	0.10	164
9	5.54	22.19	6.21	10.23	17.97	12.35	0.12	0.07	3.63	ND	0.00	0.07	0.85	0.01	40.10	0.06	280
10	6.34	56.17	33.07	14.91	51.60	88.77	3.54	0.04	12.60	ND	0.29	0.25	1.19	0.02	136.34	0.25	284
11	6.27	35.04	36.35	17.83	28.74	160.34	1.71	0.00	8.19	ND	0.00	0.24	1.88	0.02	251.93	0.23	446
13	6.86	103.80	19.15	21.75	51.51	33.39	5.23	0.00	24.84	ND	0.00	0.14	1.27	0.04	222.15	0.21	500
14	5.70	52.44	41.59	19.44	21.56	99.53	2.65	0.00	8.73	ND	0.00	0.20	1.22	0.03	46.94	0.23	450
15	6.05	65.39	15.90	23.10	39.95	21.97	5.32	0.00	11.26	ND	0.29	0.17	1.98	0.04	75.81	0.23	444
16	5.65	23.81	5.47	10.63	23.40	12.66	0.00	0.00	4.46	ND	0.00	0.17	1.28	0.01	39.86	0.19	188
17	7.60	35.70	48.71	17.95	55.90	279.91	2.06	0.00	10.03	ND	0.00	0.19	2.04	0.05	188.52	0.22	386
18	5.56	48.09	255.10	16.87	64.88	2,876.10	5.81	0.01	0.01	ND	1.43	0.48	6.43	0.02	57.69	5.80	1,850
19	5.27	36.45	124.66	15.61	20.59	1,412.70	4.36	0.00	0.00	ND	0.09	0.14	1.49	0.01	42.82	2.55	306
20	5.86	36.46	82.25	15.83	19.52	487.98	3.04	0.00	0.00	ND	0.00	0.11	1.14	0.03	148.57	0.54	406

(a) Evolution and Pollution, A.D. Bradshaw and T. McNeilly, Arnold 1981.

(b) The Nature and properties of Soils, Nyle C Brady, Macmillian 1974.

(c) ND - Not Detectable.

Table 3 Analyses of Soil Copper/Cobalt Content, 2006

Site Number	Horizon Depth		pH (H_2O)	pH-KCl	CEC cmol(+)/kg	Base Saturation %	Exch Na cmol(+)/kg	Exch K cmol(+)/kg	Exch Ca cmol(+)/kg	Exch Mg cmol(+)/kg	Exch_ Acidity cmol(+)/kg	P mg/kg	Clay %	Sand %	Silt %	Texture	Org_ C %	Total N %	C:N Ratio	Cu mg/kg	Co mg/kg
	Top	Bottom																			
SMZ002	0	11	5.81	n/a	4.403	32	0.127	0.106	0.691	0.463	n/a	20.50	16.0	59.5	24.5	SL	1.24	n/a	n/a	n/a	n/a
SMZ002	11	32	4.98	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	5.03	22.0	51.5	26.5	L	n/a	n/a	n/a	n/a	n/a
SMZ002	32	52	4.57	4.10	n/a	n/a	n/a	n/a	n/a	n/a	0.908	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SMZ009	0	21	5.94	n/a	12.902	53	0.107	0.459	3.633	2.637	n/a	4.41	24.0	65.4	10.6	L-SCL	4.96	0.187	26:1	2021.9	294.77
SMZ009	21	37	5.70	4.35	5.675	29	0.104	0.141	0.551	0.837	0.828	1.60	22.0	53.7	24.3	L-SCL	n/a	n/a	n/a	1922.1	799.78
SMZ021	10	21	6.16	n/a	7.244	51	0.112	0.410	1.133	2.062	n/a	4.09	22.0	53.1	24.9	L-SCL	1.56	0.076	20:1	n/a	n/a
SMZ021	21	44	6.04	4.46	6.307	36	0.108	0.296	0.478	1.417	0.364	2.14	32.0	45.8	22.2	CL	n/a	n/a	n/a	n/a	n/a
SMZ022	0	9	6.57	n/a	17.237	62	0.141	0.744	4.396	5.460	n/a	7.66	22.0	34.7	43.3	L	2.60	0.163	16:1	n/a	n/a
SMZ022	9	30	5.94	n/a	13.281	38	0.121	0.571	0.480	3.817	0.604	1.56	32.0	27.2	40.8	CL	n/a	n/a	n/a	n/a	n/a
SMZ024	6	35	5.28	n/a	6.833	17	0.101	0.275	0.406	0.407	1.264	2.05	28.0	50.0	22.0	SCL	0.64	0.142	5:1	n/a	n/a
SMZ027	0	11	6.24	n/a	7.914	64	0.100	0.399	1.672	2.867	0.196	3.12	24.0	45.8	30.2	L	2.05	0.042	48:1	n/a	n/a
SMZ027	11	35	6.21	4.49	9.053	30	0.104	0.251	0.453	1.870	0.360	1.34	32.0	40.0	28.0	CL	n/a	n/a	n/a	n/a	n/a
SMZ045	0	47	5.64	n/a	10.449	14	0.095	0.233	0.586	0.528	1.120	3.29	42.0	44.6	13.4	CL-C	0.68	0.044	15:1	n/a	n/a
SMZ045	47	121	5.80	4.16	7.058	20	0.113	0.435	0.459	0.381	0.836	1.92	48.0	35.0	17.0	C	n/a	n/a	n/a	n/a	n/a
SMZ063	0	12	6.14	n/a	7.890	78	0.140	0.655	1.435	3.943	0.198	5.74	22.0	33.6	44.4	L	1.84	0.125	15:1	n/a	n/a
SMZ063	12	37	5.78	4.04	10.120	50	0.124	0.781	0.423	3.700	0.929	1.47	32.0	26.4	41.6	CL	n/a	n/a	n/a	n/a	n/a
SMZ055	0	17	6.46	n/a	4.763	78	0.112	0.305	1.409	1.900	0.165	4.98	24.0	49.6	26.4	L	1.19	0.060	20:1	n/a	n/a
SMZ055	17	66	5.81	n/a	11.047	21	0.091	0.413	0.585	1.206	0.343	2.63	44.0	34.7	21.3	C	n/a	n/a	n/a	n/a	n/a
SMZ055	66	110	5.66	4.36	9.580	21	0.112	0.369	0.497	1.034	0.439	1.92	46.0	32.4	21.6	C	n/a	n/a	n/a	n/a	n/a
SMZ049	22	46	6.23	4.49	7.296	73	0.117	0.661	1.312	3.206	0.335	2.00	28.0	36.0	36.0	L-CL	n/a	n/a	n/a	n/a	n/a
SMZ049	0	12	6.64	n/a	9.722	88	0.127	0.520	4.605	3.352	0.118	2.49	22.0	39.6	38.4	L	1.65	0.114	14:1	n/a	n/a
SMZ042	0	29	6.70	n/a	26.232	94	0.149	0.396	14.482	9.559	0.124	10.77	28.0	21.5	50.5	SiL	6.22	0.247	25:1	n/a	n/a
SMZ042	29	42	5.98	4.41	12.006	76	0.128	1.337	0.741	6.889	0.356	1.43	32.0	36.8	31.2	CL	n/a	n/a	n/a	n/a	n/a

n/a = Not applicable.

APPENDIX B2.4-V

FOOD AND AGRICULTURE ORGANIZATION (FAO) LAND CAPABILITY ASSESSMENT

1 AGRICULTURAL LAND SUITABILITY

1.1 INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO) uses a land suitability system based on soil suitability. Suitability is defined as the adaptability of a given area for a specific kind of land use (FAO 1976). The FAO land suitability system uses a two-stage approach to determine land suitability:

- Stage 1 is mainly concerned with qualitative land evaluation.
- Stage 2 consists of an economic and social analysis (Stage 2 does not necessarily need to be completed).

The FAO land suitability system is a framework around which national and local systems can be constructed. The land uses are defined as closely as the purposes and soil survey intensity require. In reconnaissance surveys, this may be the major kinds of land use (Young 1976). The system is flexible and is based on the following principles:

- Land suitability is assessed and classified with respect to specified kinds of use. The qualities of each type of land, such as moisture availability or liability to flooding, are compared with the requirements of each use. Thus the land itself and the land use are equally fundamental to land suitability evaluation.
- Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land. Suitability for each use is assessed by comparing the required input, such as labor, fertilizers or road construction, with the goods produced or other benefits obtained.
- A multidisciplinary approach is required. When completing quantitative evaluation the comparison of benefits and inputs in economic terms plays a major part in determining suitability.
- Agricultural suitability ratings are made in terms relevant to the physical, economic and social context of the area concerned.
- Suitability refers to use on a sustained basis and environmental degradation is considered when assessing suitability.
- Suitability evaluation involves comparison of more than a one kind of land use. Evaluation is only reliable if benefits and inputs from any given kind of use can be compared with at least one, and usually several different, alternatives. (FAO 1976).

The FAO land suitability system is hierarchal in structure (Figure 1). The four levels in the hierarchy of land suitability categories are land suitability order, land suitability classes, land suitability subclasses and land suitability units (Table 1).

Figure 1 Structure of the Food and Agriculture Organization of the United Nations Land Suitability Classification

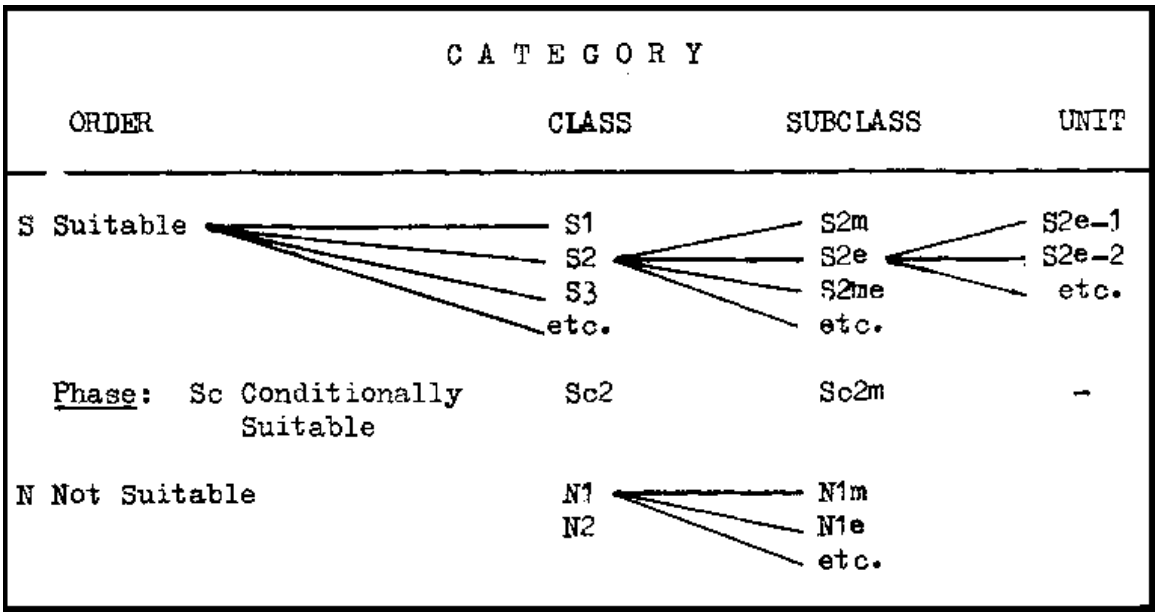


Table 1 Food and Agriculture Organization of the United Nations Land Suitability Categories

i. Land Suitability Orders	reflecting kinds of suitability
ii. Land Suitability Classes	reflecting degrees of suitability within Orders
iii. Land Suitability Subclasses	reflecting kinds of limitation, or main kinds of improvement measures required, within Classes
iv. Land Suitability Units	reflecting minor differences in required management within Subclasses

1.2 LAND SUITABILITY ORDERS

Land suitability is classified into two orders: Suitable (S) and Not Suitable (N). Suitable land is defined as “land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources”. Non Suitable land is defined as “land which has qualities that appear to preclude sustained use of the kind under

consideration". Land may be classed as Not Suitable for a given use for a number of reasons such as the risk of severe environmental degradation (i.e. cultivation of steep slopes) or because the economic value of the expected benefits does not justify the expected costs of the inputs that would be required. (FAO 1976).

1.2.1 Land Suitability Classes

There are several land suitability classes for both Suitable (S) and Non Suitable (N) orders. Suitability classes for Suitable land reflect the degrees of suitability. Generally three land suitability classes are used (Table 2).

Table 2 Common Food and Agriculture Organization of the United Nations Land Suitability Classes for the Suitable Land Orders

Class S1 Highly Suitable	land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level
Class S2 Moderately Suitable	land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on Class S1 land
Class S3 Marginally Suitable	land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified

There are two land suitability classes for Non Suitable Land (Table 3).

Table 3 Non Suitable Land Classes

Class N1 Currently Not Suitable	land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner
Class N2 Permanently Not Suitable	land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner

1.2.2 Conditional Suitability

Conditionally Suitable (CS) is a phase of Suitable Land Order (S) that defines when land is suitable provided that certain conditions are fulfilled. In the FAO

land suitability system the Conditionally Suitable (CS) phase is avoided wherever possible. It is only used when:

- The land is either not suitable or belongs to the lowest suitable class unless the specified condition(s) are in place.
- The Conditional Suitability should be at least two classes higher than equivalent suitability class.
- The extent of the conditionally suitable land is very small with respect to the total study area.

1.3 LAND SUITABILITY SUBCLASSES

Land suitability subclasses reflect kinds of limitations (i.e., moisture deficiency, erosion hazard) for Suitable land. Subclasses are designated by lower-case letters and the number of subclasses distinguishes lands within a class likely to differ significantly in their management requirements or potential for improvement due to differing limitations.

Land within the Not Suitable Order may be divided into suitability subclasses according to kinds of limitation but this is not usually done since land will not be managed for agriculture.

1.4 LAND SUITABILITY UNITS

Land suitability units are subdivisions of a subclass that differ from each other in their production characteristics or in minor aspects of their management requirement. There is no limit to the number of units recognized within a subclass.

The land suitability subclasses are described below:

Topography - (land suitability subclass - t) Slope effects agricultural land suitability because of the increase potential for water erosion and decreasing the uniformity of growth of crops.

Erosion - (land suitability subclass - e) Erosion effects agricultural land suitability because of the loss in soil nutrients, organic matter, productivity and the difficulty in farming on land with rills and gullies.

Depth to Lithic Contact or Rooting Depth - (land suitability subclass - r) Soil with an impediment or barrier to root growth effects agricultural land suitability because the ability of plants to exploit soil water and nutrients.

Soil acidity (land suitability subclass - a) Low soil pH have several effects on agricultural land suitability. Mineral deficiencies and aluminum toxicity increase at low soil pH. Soil microbial activity at lower pH values tends to convert organic minerals to soluble inorganic forms. Soils with a pH less than 5.0 are considered strongly acidic. Below this value aluminum (Al^{3+}) ions progressively replace hydrogen (H^{+}) ions and aluminum toxicity can become a problem (Young, 1989). High levels of aluminum (Al^{3+}) and manganese (Mn^{2+}) at low pH may be toxic to some crops, have an adverse effect on root growth, cause phosphorus to become immobile and unavailable to plants and effects the translocation of nutrients. Fixation of phosphorus is also most serious when soil pH is below 5.0 (Brady, 1974).

Low Fertility - (land suitability subclass - f) Nutrients – Low fertility effects agricultural land suitability since there are low nutrient levels for plant growth and a limited capacity for holding nutrient additions or reserves. A common measure of soil fertility is cation exchange capacity (CEC). Soils with low CEC are generally low in nutrients and are highly limited in retaining nutrient reserves.

Coarse Fragment Content (land suitability subclass – p) High coarse fragment content effects agricultural land suitability since there is less soil moisture available to plants and coarse fragments hinder tillage and seedbed preparation

Cobalt and Copper toxicity (land suitability subclass - n) High levels of copper cobalt in soils effects agricultural land suitability because they are reported to be phytotoxic.

Soil Organic Matter - (land suitability subclass - o) Low levels of soil organic matter effects agricultural land suitability because the nutrient availability of phosphorus, nitrogen and carbon diminishes with decrease in organic matter. Soil organic matter limitation is closely related to the fertility limitation.

APPENDIX B2.4-VI

ROCK AND SOIL STRENGTH CLASSIFICATION

Table 1 Intact Material (Rock and Soil) Strength Classification (ISRM Standard 1978)

Grade	Description	Field Identification	Approximate Range of Uniaxial Compressive Strength (MPa)
G	granular soil	cohesionless, friable, granular soil, sand	0
S2	soft clay	easily penetrated several centimeters with a steel nail	<0.025
S3	firm clay	can be penetrated several centimeters with thumb with moderate effort crumbles under light pressure from a nail	0.025 to 0.1 (< 1.0 on pocket pen)
S4	stiff clay	readily indented by thumb, but penetrated only with great effort crumbles under moderate pressure from a nail	0.10 to 0.25 (1.0 to 2.5 on pocket pen)
R0	extremely weak rock	indented by thumbnail	0.25 to 1.0 (> 2.5 on pocket pen)
R1	very weak rock	crumbles under firm blows with point of geological hammer, can be peeled by a pocket knife	1.0 to 5.0 (pocket pen maxed out)
R2	weak rock	can be peeled by a pocket knife with difficulty, shallow indentations made by firm blow with point of geological hammer	50 to 25
R3	medium strong rock	cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow or geological hammer	25 to 50
R4	strong rock	specimen requires more than one blow of geological hammer to fracture it	50 to 100
R5	very strong rock	specimen requires many blows of geological hammer to fracture it	100 to 250
R6	extremely strong rock	specimen can only be chipped with geological hammer	>250

[(a)] Reference: Brown. 1981. "Suggested Methods for Rock Characterization Testing and Monitoring", International Society for Rock Mechanics.

APPENDIX B2.5-I

DETERMINING THE VALUE OF A VISUAL RESOURCE

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1 DETERMINING THE VALUE OF A VISUAL RESOURCE

In order to reach an understanding of the effect of development on a landscape resource, it is necessary to consider the different aspects of the landscape as described in this report.

1.1 LANDSCAPE ELEMENTS AND CHARACTER

The individual elements that make up the landscape include prominent or eye-catching features such as hills, valleys, woods, trees, water bodies, buildings and roads. They are generally quantifiable and can be easily described.

Landscape character is the description of pattern, resulting from particular combinations of natural (physical and biological) and cultural (land use) factors and how people perceive these. The visual dimension of the landscape is a reflection of the way in which these factors create repetitive groupings and interact to create areas that have a specific visual identity. The process of landscape character assessment can increase appreciation of what makes the landscape distinctive and what is important about an area. The description of landscape character thus focuses on the *nature of the land*, rather than the response of a viewer.

1.2 LANDSCAPE QUALITY

This section is adapted from Crawford (1994) and The Visual Resource Management System, developed by The Bureau of Land Management (BLM) in the Department of the Interior of the US Government.

Studies for perceptual psychology have shown human preference for landscapes with a higher visual complexity particularly in scenes with water, over homogeneous areas. On the basis of contemporary research landscape quality increases when:

- Topographic ruggedness and relative relief increase - Topography becomes more interesting as it gets steeper or more massive, or more severely or universally sculptured.
- Water forms are present - The degree to which water dominates the scene is the primary consideration in selecting the rating score.
- Color in the landscape is attractive – It considers the overall color(s) of the basic components of the landscape (e.g., soil, rock, vegetation, etc.)

as they appear during seasons or periods of high use. Key factors to use when considering "color" are variety, contrast, and harmony.

- Diverse patterns of grasslands and trees occur – It gives primary consideration to the variety of patterns, forms, and textures created by plant life. It considers short-lived displays when they are known to be recurring or spectacular and also smaller scale vegetational features which add striking and intriguing detail elements to the landscape (e.g., gnarled or wind beaten trees).
- Landscape types are scarce - This factor provides an opportunity to give added importance to one or all of the scenic features that appear to be relatively unique or rare within one physiographic region. There may also be cases where a separate evaluation of each of the key factors does not give a true picture of the overall scenic quality of an area. Often it is a number of not so spectacular elements in the proper combination that produces the most pleasing and memorable scenery - the scarcity factor can be used to recognize this type of area and give it the added emphasis it needs.
- Natural landscape increases and man-made landscape decreases.
- Land use compatibility increases and land use edge diversity decreases - Cultural modifications in the landform/water, vegetation, and addition of structures should be considered and may detract from the scenery in the form of a negative intrusion or complement or improve the scenic quality of a unit.

Aesthetic value 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 (Ramsay 1993). Thus aesthetic value encompasses more than the seen view, visual quality or scenery, and includes atmosphere, landscape character and sense of place (Schapper 1993).

Aesthetic appeal (value) is considered high when the following are present (Ramsay 1993):

- *Abstract qualities*: such as the presence of vivid, distinguished, uncommon or rare features or abstract attributes.
- *Evocative responses*: the ability of the landscape to evoke particularly strong responses in community members or visitors.
- *Meanings*: the existence of a long-standing special meaning to a particular group of people or the ability of the landscape to convey special meanings to viewers in general.

- *Landmark quality*: a particular feature that stands out and is recognised by the broader community.

1.3 SENSE OF PLACE

Central to the concept of a sense of place is that the place requires uniqueness and distinctiveness. The primary informant of these qualities is the spatial form and character of the natural landscape together with the cultural transformations and traditions associated with historic use and habitation. According to Lynch (1992) sense of place "is the extent to which a person can recognize or recall a place as being distinct from other places - as having a vivid, or unique, or at least particular, character of its own". Sense of place is the unique value that is allocated to a specific place or area through the cognitive experience of the user or viewer. In some cases these values allocated to the place are similar for a wide spectrum of users or viewers, giving the place a universally recognized and therefore, strong sense of place.

1.4 SCENIC BEAUTY OF VISUAL RESOURCE

In determining the scenic quality of the visual resource both the objective and the subjective or aesthetic factors associated with the landscape are considered. Many landscapes can be said to have a strong sense of place, regardless of whether they are considered to be scenically beautiful but where landscape quality, aesthetic value and a strong sense of place coincide - the visual resource or perceived value of the landscape is considered to be very high.

When considering both objective and subjective factors associated with the landscape there is a balance between landscape character and individual landscape features and elements, which would result in the values as follows in Tables 1 and 2.

Table 1 Value of Visual Resource [(a)]

High (Distinct)	Moderate (Common)	Low (Minimal)
Areas that exhibit a very positive character with valued features that combine to give the experience of unity, richness and harmony. These are landscapes that **may** be considered to be of particular importance to conserve and which may be sensitive change in general and which may be detrimental if change is inappropriately dealt with.	Areas that exhibit positive character but which may have evidence of alteration to /degradation/erosion of features resulting in areas of more mixed character. Potentially sensitive to change in general; again change may be detrimental if inappropriately dealt with but it may not require special or particular attention to detail.	Areas generally negative in character with few, if any, valued features. Scope for positive enhancement frequently occurs.

[(a)] Derived from The Landscape Institute with the Institute of Environmental Management and Assessment (2002).

Table 2 Scenic Quality Inventory and Evaluation Chart [(a)]

Key factors	Rating Criteria and Score		
Landform	High vertical relief as expressed in prominent cliffs, spires, or massive rock outcrops, or severe surface variation or highly eroded formations including major badlands or dune systems; or detail features dominant and exceptionally striking and intriguing such as glaciers. **5**	Steep canyons, mesas, buttes, cinder cones, and drumlins; or interesting erosional patterns or variety in size and shape of landforms; or detail features which are interesting though not dominant or exceptional. **3**	Low rolling hills, foothills, or flat valley bottoms; or few or no interesting landscape features. **1**
Vegetation	A variety of vegetative types as expressed in interesting forms, textures, and patterns. **5**	Some variety of vegetation, but only one or two major types. **3**	Little or no variety or contrast in vegetation. **1**
Water	Clear and clean appearing, still, or cascading white water, any of which are a dominant factor in the landscape. **5**	Flowing, or still, but not dominant in the landscape. **3**	Absent, or present, but not noticeable. **0**
Color	Rich color combinations, variety or vivid color; or pleasing contrasts in the soil, rock, vegetation, water or snow fields. **5**	Some intensity or variety in colors and contrast of the soil, rock and vegetation, but not a dominant scenic element. **3**	Subtle color variations, contrast, or interest; generally mute tones. **1**
Influence of adjacent scenery	Adjacent scenery greatly enhances visual quality. **5**	Adjacent scenery moderately enhances overall visual quality. **3**	Adjacent scenery has little or no influence on overall visual quality. **0**
Scarcity	One of a kind; or unusually memorable, or very rare within region. Consistent chance for exceptional wildlife or wildflower viewing, etc. *** 5+**	Distinctive, though somewhat similar to others within the region. **3**	Interesting within its setting, but fairly common within the region. **1**
Cultural modifications	Modifications add favorably to visual variety while promoting visual harmony. **2**	Modifications add little or no visual variety to the area, and introduce no discordant elements. **0**	Modifications add variety but are very discordant and promote strong disharmony. **-4**

(a) Developed by the Bureau of Land Management [BLM], in The Department of the Interior of the US Government.

APPENDIX B2.9-1

SOUND TERMINOLOGY

Sound Terminology

The following descriptions of key concepts and definitions used in this evaluation are provided to guide the non-technical reader:

- "Sound" or "sound emissions" refers to the acoustic energy generated by natural or man-made sources, including the project activities.
- "Noise" or "noise levels" refers to the levels that can be heard or measured at a receiver.
- A noise "receiver" is a location where measurements or predictions of noise levels are made.
- The "volume" of a sound or noise is expressed on a logarithmic scale, in 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.
- Sound emissions and noise levels also have a "frequency". The human ear does not respond to all frequencies in the same way. Mid-range frequencies are most readily detected by the human ear, while low and high frequencies are harder to hear. Environmental noise levels are usually presented as "A-weighted" decibels (or dBA), which incorporates the frequency response of the human ear. While low frequency noise may not be "heard", it can often be felt.
- Outdoor noise is usually expressed as an "equivalent noise level" (L_{eq}), which is a logarithmic average of the measured or predicted noise levels over a given period of time. This type of average takes into account the natural variability of sound.

APPENDIX B2.10-1

HYDROGEOLOGY LABORATORY RESULTS

Table 1 Unfiltered Samples Analyses on an As-Received Basis (Wet Season 2006)

SAMPLE MARKS	Blank	Water Samples										
	B 3	GW 1 or KAMESALE	GW 2	GW 3	GW 4	GW 5	GW 6	GW 7	GW 8	GW9	GW 10 or P3	GW 11
Source Type		Spring	Spring	Spring	Spring	Spring	Spring	Spring	Spring	Spring	Well	Spring
pH Value @ 23°C *	5.7	7.7	7.8	7.3	7.4	7.4	7.3	7.4	7.9	7.4	7.3	7.4
conductivity mS/m @ 25°C *	0.609	73.9	7.02	81.1	106	116	78.7	57.2	49	91.4	74.2	82.2
Total Dissolved Solids *	**63**	**418**	**410**	**486**	**628**	**700**	**500**	**344**	**288**	**698**	**440**	**524**
calcium, Ca *	0.6	56	66	57	67	52	60	48	40	86	54	64
magnesium, Mg *	<0.1	67	61	80	113	140	72	49	41	72	68	74
Total Hardness as mg/L $CaCO_3$	**1.5**	**416**	**416**	**472**	**632**	**706**	**446**	**322**	**269**	**511**	**415**	**464**
sodium, Na	1.6	1.8	6.4	5.4	5.6	4.6	3.6	3.6	4.4	3	2.7	6.8
potassium, K *	<0.1	3.2	1.2	1.4	1.6	1.2	2.2	2.2	1.5	1.9	2.7	1.4
Total Alkalinity as mg/L $CaCO_3$	**8**	**424**	**412**	**468**	**628**	**696**	**428**	**316**	**272**	**392**	**400**	**452**
bicarbonate, HCO_3	10	517	502	561	766	848	522	385	332	478	488	551
carbonate, CO_3	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
chloride, Cl	2.6	3.1	4.2	3.7	2.6	2.6	3.7	5.2	4.2	4.7	5.2	3.7
sulphate, SO_4	1.8	1.3	1.3	5.6	12	12.2	17.1	2.4	2.6	94	23	20
nitrate, as NO_3	2.6	<0.1	4	5.4	4.5	3.3	2	3.1	1.8	3.6	1.7	2.2
nitrate as N	0.6	<0.1	0.9	1.2	1	0.7	0.5	0.7	0.4	0.8	0.4	0.5
nitrite as N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
fluoride, F	1.2	0.3	0.5	0.7	0.7	0.5	0.5	0.3	0.3	0.3	0.4	0.4
Total Suspended Solids	**<1**	**15**	**21**	**2**	**<1**	**<1**	**<1**	**14**	**11**	**<1**	**<1**	**<1**
total solids	63	433	431	488	628	700	500	358	799	698	440	524
oil & grease	5	13	3.4	3.4	4.6	2.2	2.8	2.8	2.2	2.6	2.4	1.4
free and saline ammonia as N	0.5	<0.1	0.2	0.4	0.6	0.6	0.5	0.4	0.7	<0.1	<0.1	<0.1
Total Kjeldahl Nitrogen as N	**1.6**	**1.5**	**2.9**	**1.7**	**1.5**	**2.1**	**1.6**	**2**	**5.8**	**1.8**	**<0.1**	**1.3**
biochemical oxygen demand, O_2	1.1	<0.1	0.4	0.5	0.4	0.5	0.7	0.9	2.9	2	0.7	2
chemical oxygen demand, O_2	18	18	18	31	9	9	26	22	53	61	13	9
phenolic compounds as phenol	0.017	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.003	0.002	<0.001	<0.001
sulphide, S	<0.2	0.8	0.6	1.8	0.1	0.2	0.2	0.2	0.4	0.4	0.1	0.2
total organic carbon, C	<1	1.8	2.9	3.5	2.9	6.8	4.9	2.8	2.7	4.1	3	2.8
dissolved organic carbon, C	<1	1.1	2.7	2.8	1.8	5.8	2.6	1.5	1.5	1.6	2.1	2.7
mercury, Hg	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
color, (Hazen units)	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Total Phosphate, PO_4	**<0.1**	**0.2**	**0.2**	**<0.1**	**<0.1**	**<0.1**	**0.2**	**<0.1**	**0.2**	**<0.1**	**0.5**	**0.1**

All concentrations in mg/L unless otherwise noted.

Table 2a Dissolved Metal Concentrations by ICP-OES

SAMPLE MARKS	B3	GW 1 or KAMESALE	GW2	GW3	GW4	GW5	GW6	GW7	GW8	GW9	GW 10 or P3	GW11
arsenic, As	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
selenium, Se	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
aluminium, Al	0.01	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
nickel, Ni	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
manganese, Mn	<0.001	0.04	0.39	0.03	<0.001	<0.001	<0.001	0.37	0.01	<0.001	<0.001	<0.001
iron, Fe	0.001	<0.001	0.33	0.02	<0.001	0.01	0.004	0.1	0.08	0.01	<0.001	0.01
vanadium, V	0.004	0.006	0.005	0.008	0.006	0.008	0.009	0.007	0.008	0.008	0.003	0.008
zinc, Zn	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
antimony, Sb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
lead, Pb	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01
cobalt, Co	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.55	0.004	0.001	0.001	<0.001
copper, Cu	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.003	0.004	0.002	0.006	<0.002
chromium, Cr	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
silicon, Si	<0.007	14.1	17	17.2	11	16.9	14.2	10.9	12.6	11.8	11.5	16.2
tin, Sn	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
beryllium, Be	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
cadmium, Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
strontium, Sr	<0.001	0.06	0.16	0.17	0.34	0.47	0.77	0.3	0.12	0.96	0.16	0.38
boron, B	<0.006	<0.006	<0.006	<0.006	<0.006	0.01	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
uranium, U	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
molybdenum, Mo	0.002	<0.001	0.004	0.005	0.004	0.006	0.003	0.003	0.005	0.003	<0.001	0.004
barium, Ba	<0.001	0.62	0.18	0.04	0.07	0.11	0.25	0.17	0.36	0.07	0.05	0.17
silver, Ag	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.004	<0.004	<0.004	<0.004	<0.004
thorium, Th	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002

All concentrations in mg/L unless otherwise noted.

Table 2b Total Metal Concentrations by ICP-OES (continued)

SAMPLE MARKS	B 3	GW 1 or KAMESALE	GW 2	GW 3	GW 4	GW 5	GW 6	GW 7	GW 8	GW9	GW 10 or P3	GW 11
Total Metals												
arsenic, As	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
selenium, Se	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
aluminium, Al	1.5	<0.009	<0.009	<0.009	0.06	0.15	<0.009	0.67	0.97	0.12	<0.009	0.11
nickel, Ni	0.004	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.009	<0.003	0.003	<0.003	<0.003
manganese, Mn	0.03	0.08	0.39	0.05	<0.001	0.008	0.008	0.37	0.05	0.004	0.001	<0.001
iron, Fe	0.52	0.12	0.33	0.02	<0.001	0.01	0.08	0.1	0.08	0.01	<0.001	0.01
vanadium, V	0.004	0.008	0.005	0.008	0.006	0.008	0.009	0.01	0.008	0.1	0.01	0.02
zinc, Zn	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.006	<0.005	<0.005	<0.005	0.02	<0.005
antimony, Sb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
lead, Pb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	0.01	0.01	<0.01	<0.01
cobalt, Co	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.55	0.005	0.001	0.001	<0.001
copper, Cu	<0.002	0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.003	0.004	0.002	0.01	<0.002
chromium, Cr	0.005	<0.003	<0.003	<0.003	0.006	<0.003	<0.003	0.01	<0.003	<0.003	<0.003	<0.003
tin, Sn	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
beryllium, Be	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
cadmium, Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
strontium, Sr	0.001	0.14	0.16	0.17	0.34	0.47	0.77	0.3	0.12	0.96	0.37	0.38
boron, B	0.22	<0.006	0.36	0.3	0.21	0.22	0.27	0.32	0.51	0.38	<0.006	0.19
uranium, U	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
molybdenum, Mo	0.002	0.003	0.004	0.005	0.004	0.006	0.003	0.003	0.005	0.003	0.001	0.004
barium, Ba	<0.001	1.4	0.24	0.04	0.07	0.11	0.25	0.17	0.36	0.07	0.11	0.17
silver, Ag	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
thorium, Th	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002

All concentrations in mg/L unless otherwise noted.

APPENDIX B2.11-I

HISTORICAL RAINFALL AND FLOW DATA

Table 1 Flow Measurements Taken in the Dipeta River and Some Tributaries of the Dipeta River for the 1972/73 Hydrological Year (m^3/s)

Location	Dipeta Site No.1	Dipeta Site No.2	Dipeta Site No.3	Konka Gauge	Kanwezi Gauge	Shimpidi
Date	**Golder SP 16**	**Dipeta Between Konka and Kasinganga Confluences**		**Golder SP 6**	**Golder SP 13**	**Could Not Be Established**
22 May 72	1.06	-	-	0.17	-	-
20 April 72	0.94	-	-	0.15	-	-
27 April 72	0.82	-	-	0.11	-	-
3 June 72	0.77	-	-	0.09	-	-
10 June 72	0.82	-	-	0.09	-	-
17 June 72	0.69	-	-	0.08	-	-
24 June 72	0.76	-	-	0.09	-	-
1 July 72	0.76	-	-	0.08	-	-
8 July 72	0.73	-	-	0.08	-	-
15 July 72	0.74	0.27	-	0.07	-	-
22 July 72	0.76	0.24	-	0.06	-	-
29 July 72	0.71	0.24	0.23	0.07	-	-
5 Aug 72	0.68	0.22	0.23	0.06	-	-
12 Aug 72	0.70	0.25	-	0.06	-	-
19 Aug 72	0.06	-	-	0.07	-	-
26 Aug 72	0.6	0.20	0.21	0.50	-	0.13
2 Sept 72	0.67	-	-	-	-	-
9 Sept 72	0.61	0.22	-	0.04	-	-
23 Sept 72	0.62	0.22	-	0.06	-	-
30 Sept 72	-	-	-	-	-	-
7 Oct 72	-	-	-	-	-	-
14 Oct 72	0.56	0.21	-	0.04	-	-
21 Oct 72	0.62	0.22	-	0.04	-	-
28 Oct 72	0.06	0.22	-	0.08	-	-
4 Nov 72	0.67	0.22	-	0.06	-	-
11 Nov 72	0.66	0.24	-	0.07	-	-
18 Nov 72	0.70	-	-	0.07	-	-
25 Nov 72	0.79	0.5	-	0.08	-	-
02 Dec 72	0.97	0.25	-	0.36	0.09	-
9 Dec 72	0.75	0.27	-	0.17	-	-
16 Dec 72	0.96	0.28	-	0.37	-	-
23 Dec 72	0.82	0.27	-	0.17	-	-
30 Dec 72	0.91	0.30	-	2.11	-	-
6 Jan 73	1.41	0.80	-	0.67	-	-
13 Jan 73	3.89	0.30	-	0.54	-	-
27 Jan 73	1.42	0.22	-	0.50	0.05	-
3 Feb 73	-	-	-	-	-	-
14 July 97	-	-	0.24	-	-	-

- = no data available.

Table 2 One-Time Measurements Taken by SRK in July 1997

Site Number	Grid location			Stream Name / Location	Flow (m^3/s)
	X (m)	Y (m)	Z (mamsl)[(a)]		
938	235,700	322,200	1.139	Dipeta (Fungurume)	1.248
1,400	233,120	321,200	1.153	Dipeta (TFM Camp)	0.471
1,401	230,300	322,500	1.153	Dipeta	0.695
1,455	226,340	321,750	1.216	Dipeta	0.160
1,416	220,350	322,500	<1.280	Dipeta	dry
1,429	228,240	321,150	1.199	Konka near Dipeta Road	0.149
1,308	227,160	321,800	1.220	Konka crossing ridge	0.068
947	227,160	318,000	1.280	Konka National road	0.075
1,031	227,050	318,000	1.280	Kakapidi (Zakeo)	0.005
1,352	224,250	321,180	1.245	Kakapidi	0.059
1,218	236,600	321,000	-	Kalengila National road	0.111
1,310	232,480	320,850	-	Kamwezi near Dipeta	not measured
917	231,400	319,500	1.195	Kamwezi National road	0.002
1,445	218,500	323,060	1.300	Sokalwala	0.058
1,524	223,940	322,900	1.252	Shimpidi	0.116
1,608	223,100	323,760	1.290	Shimpidi	0.012
1,353	223,220	323,600	-	Shimpidi	0.020
1,540	226,650	322,380	<1.226	Kalengimiawa	dry
1,639	225,500	323,150	<1.238	Kalengimiawa	dry
943	-	225,250	-	Kalengimiawa	not measured
1,104	225,240	323,700	-	Kalengimiawa	0.007
1,648	228,900	323,360	<1.206	Kasanga	dry
1,537	-	-	-	Tenke spring	0.0002
910	230,400	322,050	<1.190	Kasangango	dry

[(a)] Z is the elevation of the water table meters above mean sea level.
- = no data available.

Table 3 summarizes the rainfall and flow monitoring data that has been collected in the area. The last column in the table indicates whether the data is available to Golder or not.

Table 3 Summary of Available Rainfall and Flow Monitoring Data

Data	Frequency of Measurement	Location	Period of Measurement	Result	Source of Information	Data Available
rainfall	daily	Lubumbashi	1962 - 1996	-	SRK 1998	yes
rainfall	daily	Kolwezi	1970 - 1980	-	SRK 1998	no
rainfall	daily	Kolwezi	1953 - 1974 (4)[(a)]	1,203 mm	SRK 1997	no
rainfall	daily	Fungurume	1973/1974 hydrological year	1,082 mm	SRK 1997. taken from a 1975 memorandum which presents the rainfall for the 1973/1974 hydrological year only	no
rainfall	unknown	Watershed Road		1,092 mm		no
rainfall	unknown	Kwatebala Hill		936 mm		no
rainfall	unknown	Kwatebala station		1,035 mm[(b)]		no
rainfall	unknown	Bangweza		1,214 mm		no
rainfall	unknown	Lukotola		1,313 mm		no
rainfall	unknown	Tenke		925 mm		no
rainfall	unknown	Zadeko		1,070 mm		no
rainfall	unknown	Mine site	1972-1973	-	SRK 1998	no
rainfall	unknown	Gécamines in Likasi	-	-	SRK 1998	no
rainfall	unknown	N'Zilo	1952 – 1974	1,110 mm	SRK 1997	no
rainfall	unknown	Pont lac Lualaba	1956 – 1974 (2) [(a)]	1,074 mm	SRK 1997	no
rainfall	unknown	Panda in Likasi	1951 – 1974 (5) [(a)]	1,216 mm	SRK 1997	no
rainfall	unknown	Kisanfanu	1956 – 1974	1,142 mm	SRK 1997	no
rainfall	unknown	Tenke Gare	1958 – 1974 (6) [(a)]	1,127 mm	SRK 1997	no
rainfall	unknown	Kambove	1963 - 1974	1,280 mm	SRK 1997	no
rainfall	unknown	Tenke-KDL	1958 – 1974 (6) [(a)]	1,121 mm	SRK 1997	no
rainfall	daily	Solwezi	1975-2004	1,290 mm	unknown	yes
rainfall by malaisse	unknown	Fungurume	1952-1974	1,160 mm in Tenke	SRK 1998	no
all types of weather data	continuous daily max. in 24 hours	at the TFM camp	June 1997 - May 1998	1,152 mm	Golder 1999 and recent downloads	yes
flow monitoring	irregular intervals	Dipeta and main tributaries	April 1972 - February 1973	-	SRK 1998	yes
flow monitoring	once by SRK	Dipeta and main tributaries	July 1997	-	SRK 1998	yes

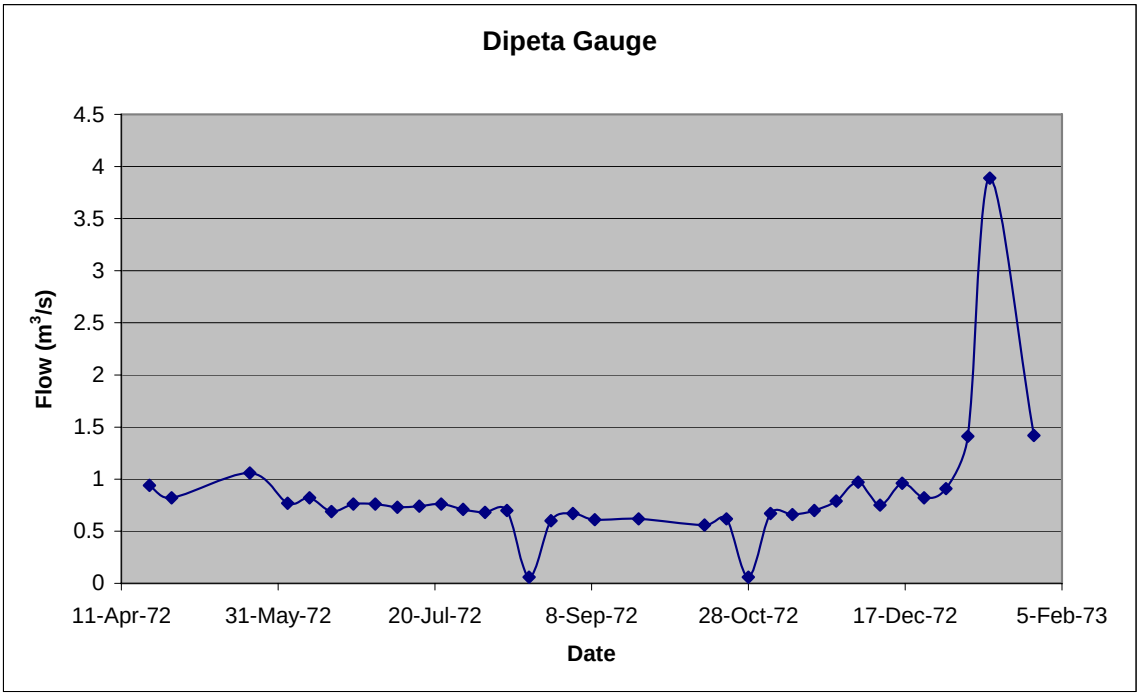
[(a)] Values in brackets denote the number of years of missing data in the record.

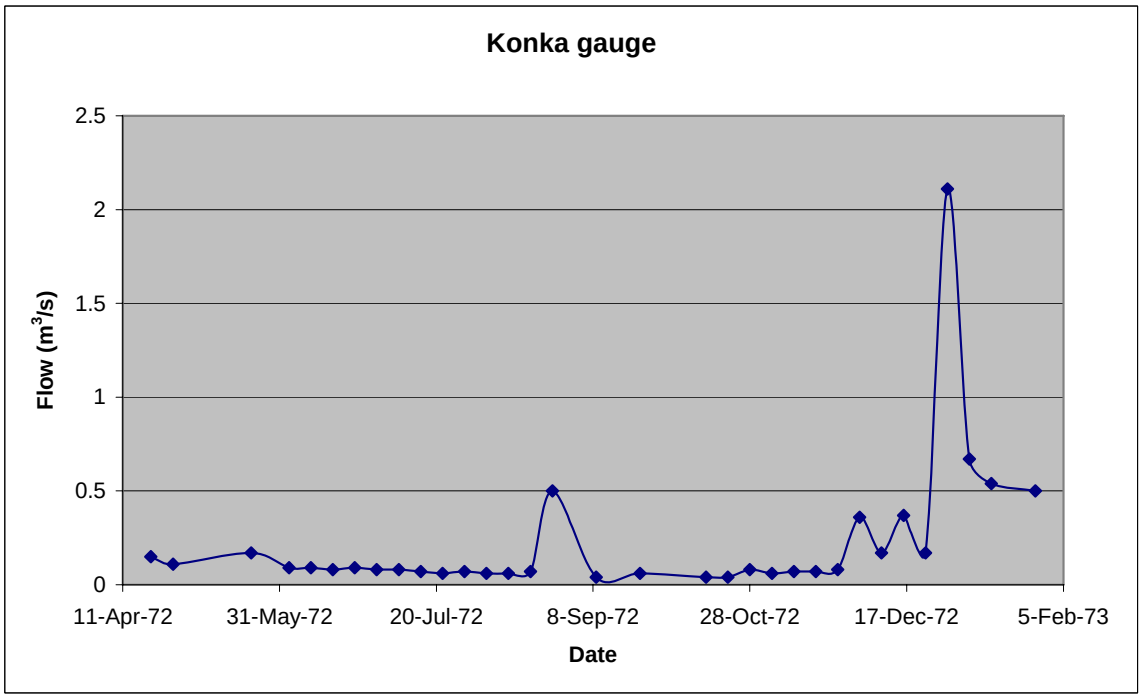
[(b)] Estimated in SRK 1997.

- = no data available.

APPENDIX B2.11-II

HYDROGRAPHS OF 1972/1973 RECORDED FLOW DATA


Dipeta Gauge
Flow (m3/s)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
11-Apr-72
31-May-72
20-Jul-72
8-Sep-72
28-Oct-72
17-Dec-72
5-Feb-73
Date


Konka gauge
Flow (m3/s)
2.5
2
1.5
1
0.5
0
11-Apr-72
31-May-72
20-Jul-72
8-Sep-72
28-Oct-72
17-Dec-72
5-Feb-73
Date

APPENDIX B2.11-III

GAUGE PLATE INSTALLATIONS

Gauge Plates Attached to Steel Poles

The gauge plates were attached to steel circular poles which were driven into sandy river beds. The gauge plates were affixed to these steel poles. An example of this is shown in Photograph 1. This method was used in small streams with deep sandy river beds.

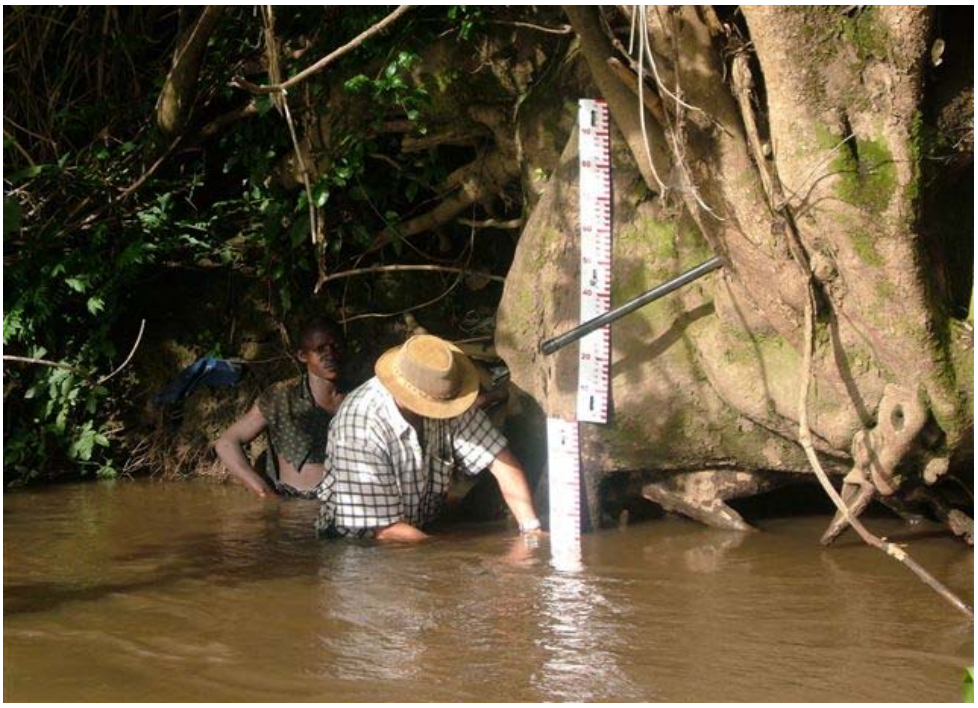
Gauge Plates Attached to Trees

The gauge plates were nailed to trees or roots that were growing in the river or on the banks of the river. An example of this is shown in Photograph 2. This method is ideal for larger rivers where high flows may wash away other forms of installations. The trees or roots had to be vertical, or near vertical to be effective. The trees or roots should also not impede the flow and cause local changes in water depths.

Gauge Plates Attached to Bridge Sections

The gauge plates were bolted to concrete bridge structures using expansion bolts. An example of this is shown in Photograph 3. This method of installation is applicable when the river passes through a concrete structure such as a bridge. Extreme care was taken when drilling the holes as a generator and an electric drill were used. We wore rubber waders, ensured that all cables were securely above water, and did not have anyone other than the person drilling the holes in the water. One person was responsible for watching the driller to ensure that cables did not accidentally drop into the water, or if the driller slipped. This person would trip the trip switch in case of an incident. A second person stood at the generator to trip the trip switch in case of an incident if the generator had to be located remote from the drilling. This person was in direct line of site of the person watching the driller. No incident occurred while drilling.

Photograph 1 **Gauge Plate Attached to a Steel Pole Driven into the Stream Bed**

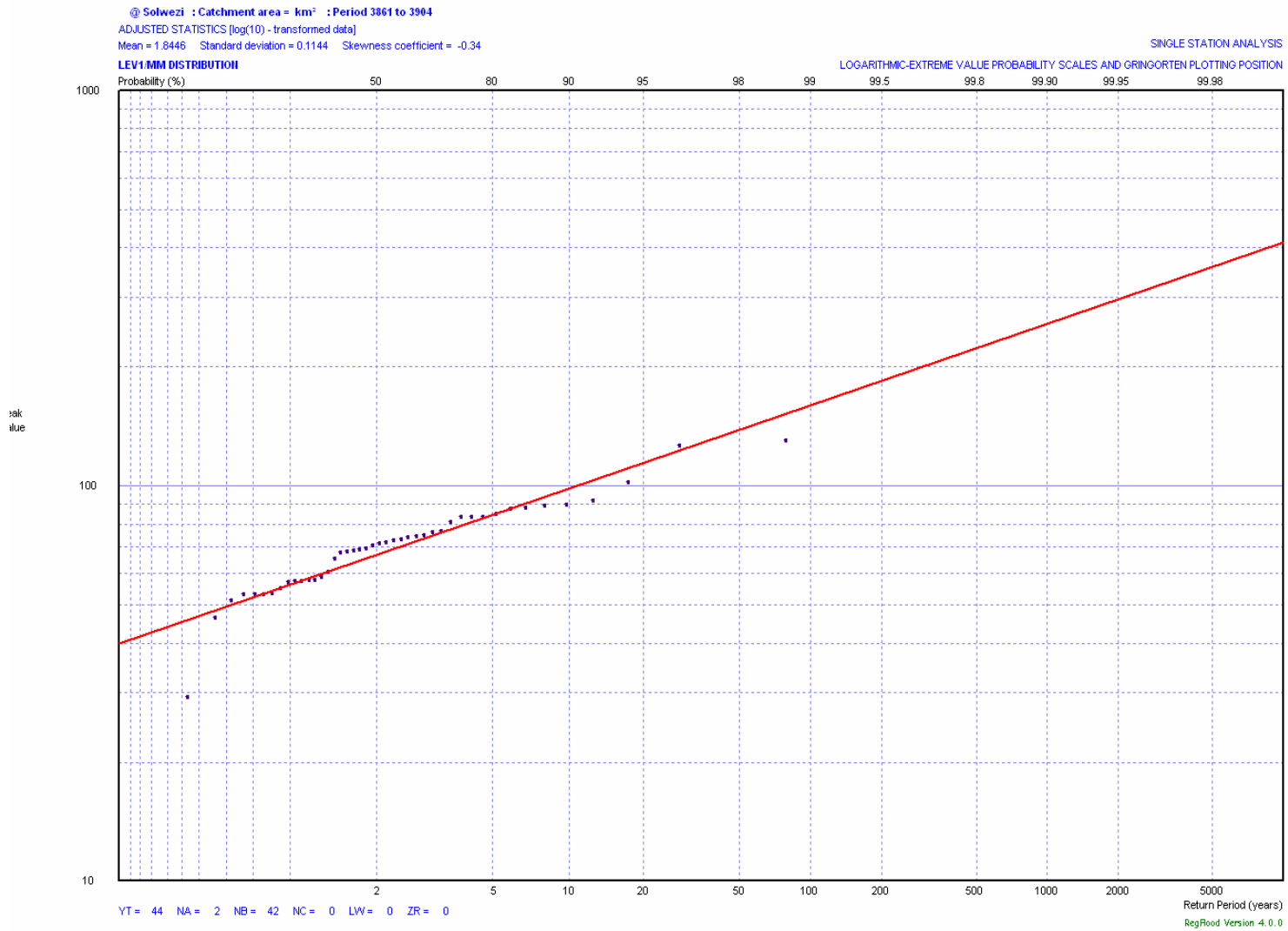


Photograph 2 **Gauge Plates Attached to a Tree**

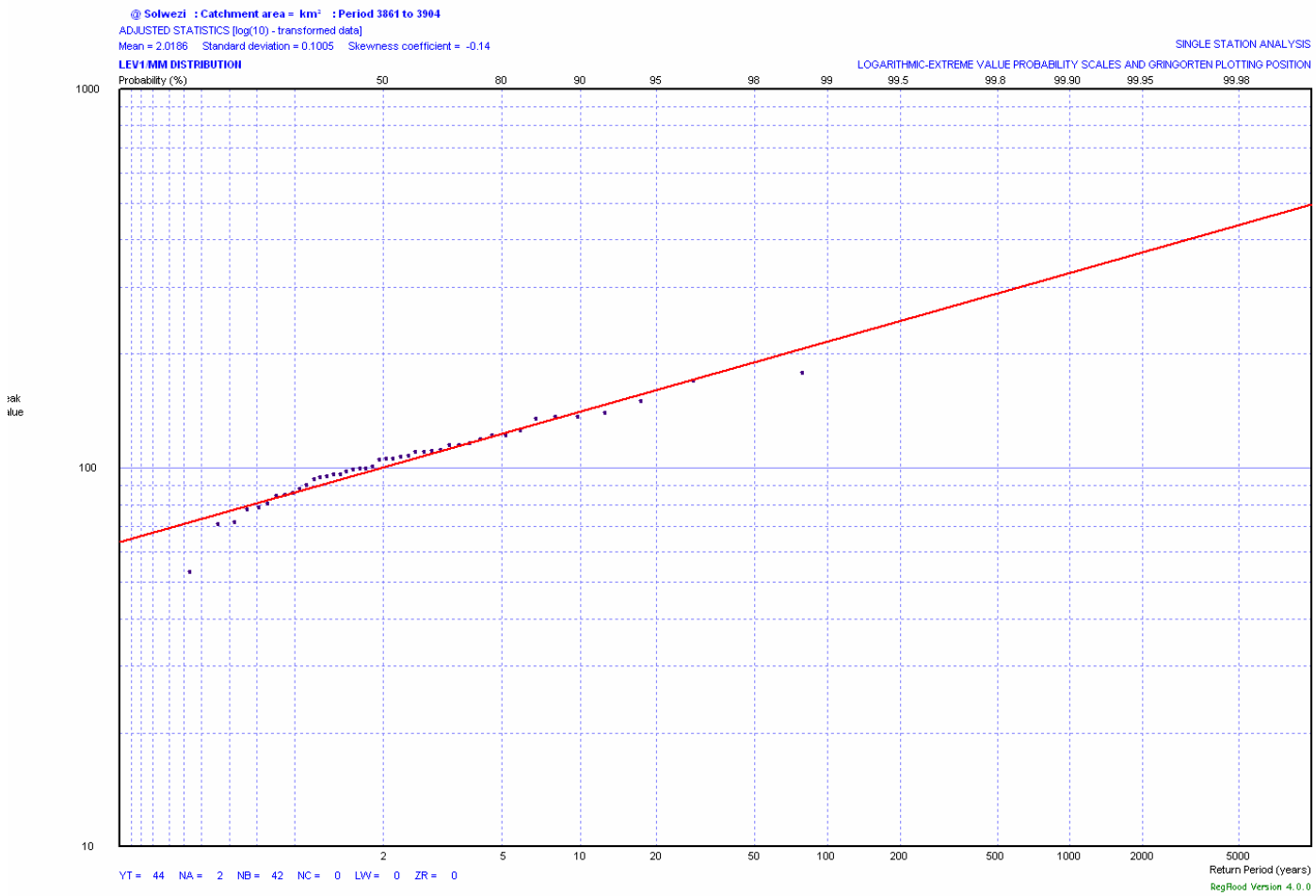
Photograph 3 Gauge Plate Attached to a Concrete Bridge Structure

APPENDIX B2.11-IV

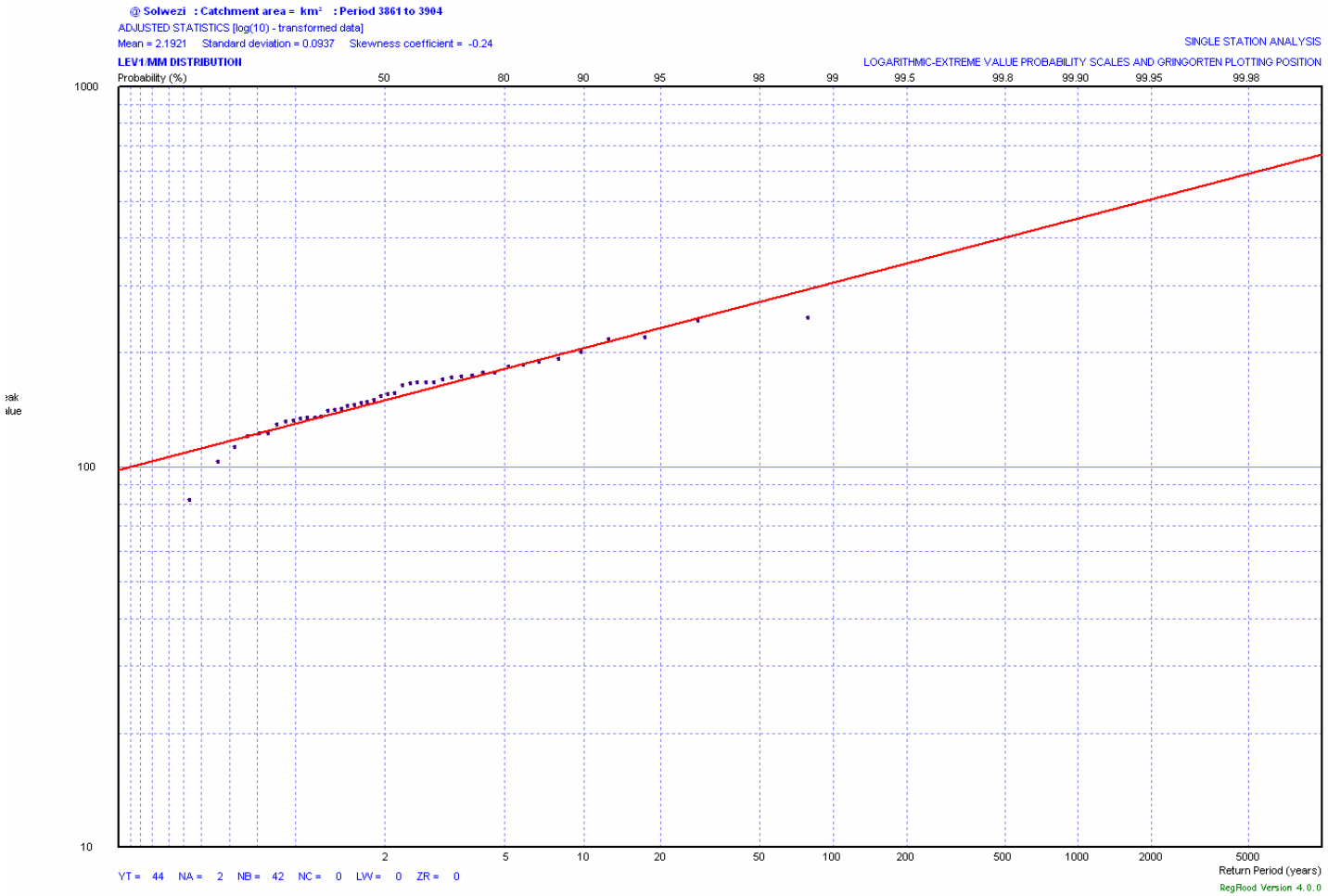
EXTREME RAINFALL PROBABILITY FITS


@ Solwezi : Catchment area = km² : Period 3861 to 3904
ADJUSTED STATISTICS [log(10) - transformed data]
Mean = 1.8446 Standard deviation = 0.1144 Skewness coefficient = -0.34
SINGLE STATION ANALYSIS
LEV1MM DISTRIBUTION
LOGARITHMIC-EXTREME VALUE PROBABILITY SCALES AND GRINGORTEN PLOTTING POSITION
Probability (%)
50
80
90
95
98
99
99.5
99.8
99.90
99.95
99.98
1000
100
10
2
5
10
20
50
100
200
500
1000
2000
5000
Return Period (years)
YT = 44 NA = 2 NB = 42 NC = 0 LW = 0 ZR = 0
RegFlood Version 4.0.0

24-Hour Fit


@ Solwezi : Catchment area = km² : Period 3861 to 3904
ADJUSTED STATISTICS [log(10) - transformed data]
Mean = 2.0166 Standard deviation = 0.1005 Skewness coefficient = -0.14
LEVI MM DISTRIBUTION
SINGLE STATION ANALYSIS
LOGARITHMIC-EXTREME VALUE PROBABILITY SCALES AND GRINGORTEN PLOTTING POSITION
Probability (%)
50
80
90
95
98
99
99.5
99.8
99.90
99.95
99.98
1000
100
10
2
5
10
20
50
100
200
500
1000
2000
5000
Return Period (years)
YT = 44 NA = 2 NB = 42 NC = 0 LW = 0 ZR = 0
RegFlood Version 4.0.0

3-Day Fit


@ Solwezi : Catchment area = km² : Period 3861 to 3904
ADJUSTED STATISTICS [log(10) - transformed data]
Mean = 2.1921 Standard deviation = 0.0937 Skewness coefficient = -0.24
SINGLE STATION ANALYSIS
LEV1/MM DISTRIBUTION
LOGARITHMIC-EXTREME VALUE PROBABILITY SCALES AND GRINGORTEN PLOTTING POSITION
Probability (%)
50
80
90
95
98
99
99.5
99.8
99.90
99.95
99.98
1000
100
10
2
5
10
20
50
100
200
500
1000
2000
5000
Return Period (years)
YT = 44 NA = 2 NB = 42 NC = 0 LW = 0 ZR = 0
RegFlood Version 4.0.0

7-Day Fit

APPENDIX B2.11-V

MEASURED FLOW DATA

Figure 1 Measured Flow Data for Dipeta

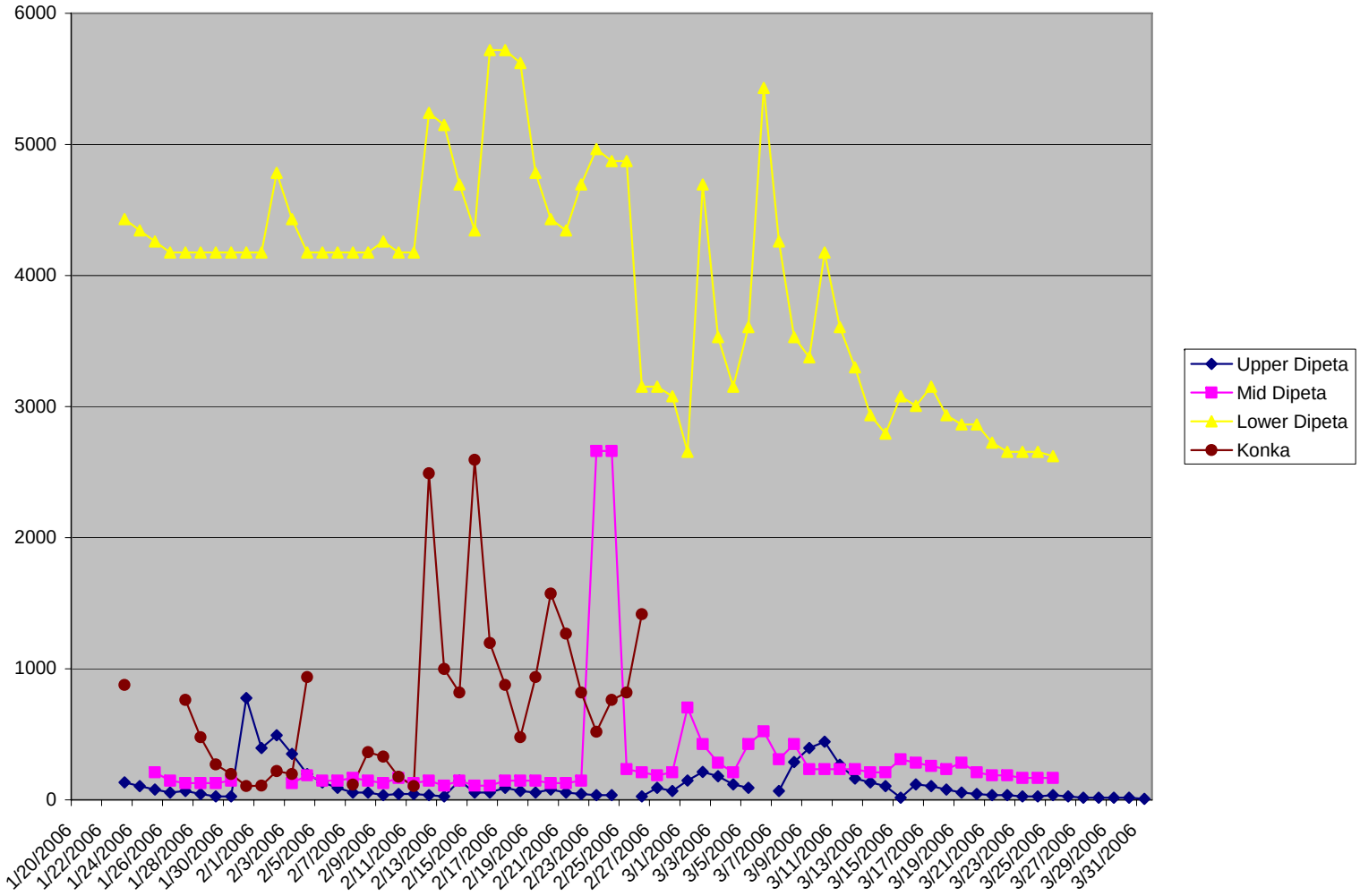


Figure 2 Measured Flow Data for Dipeta

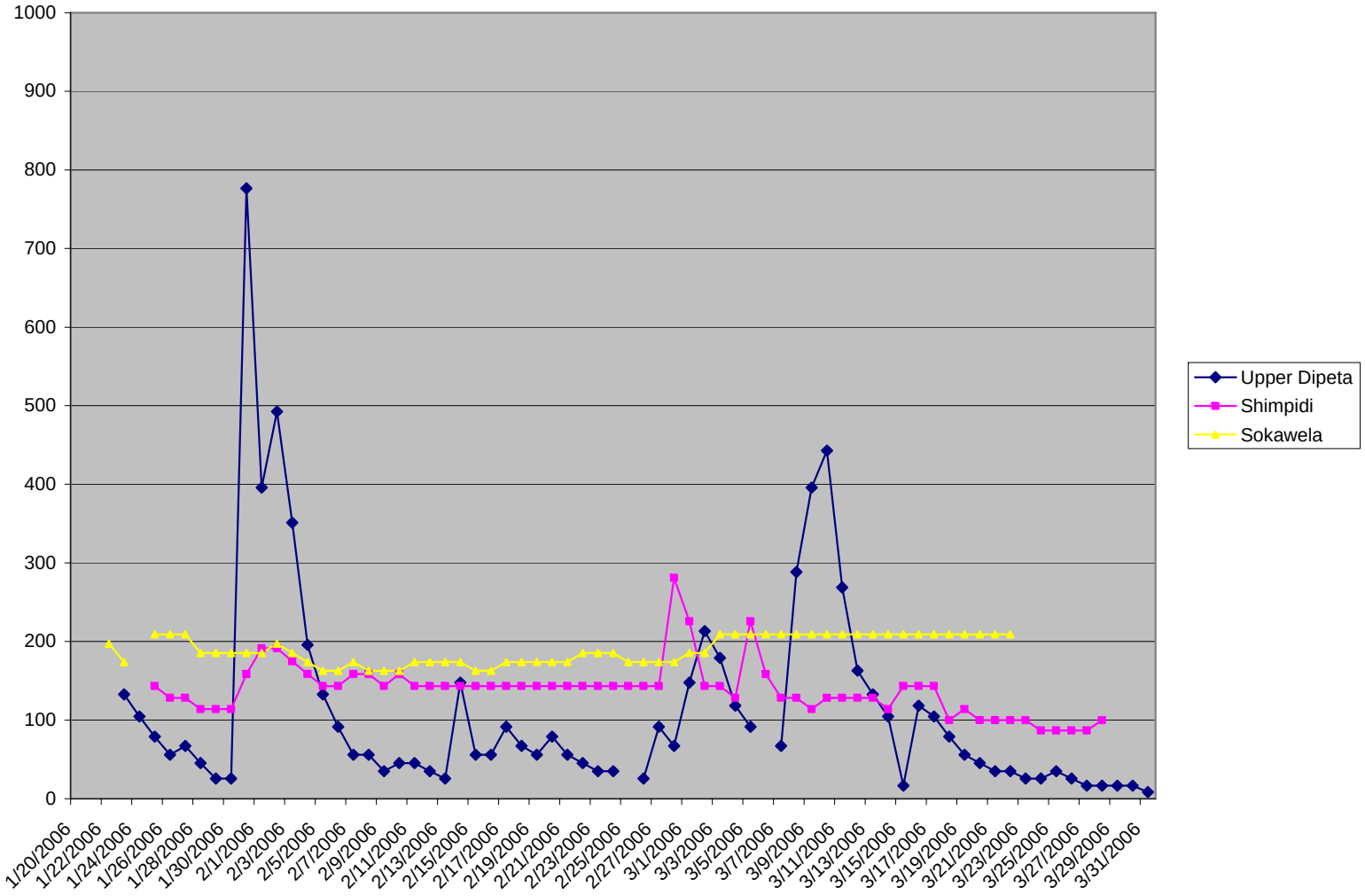
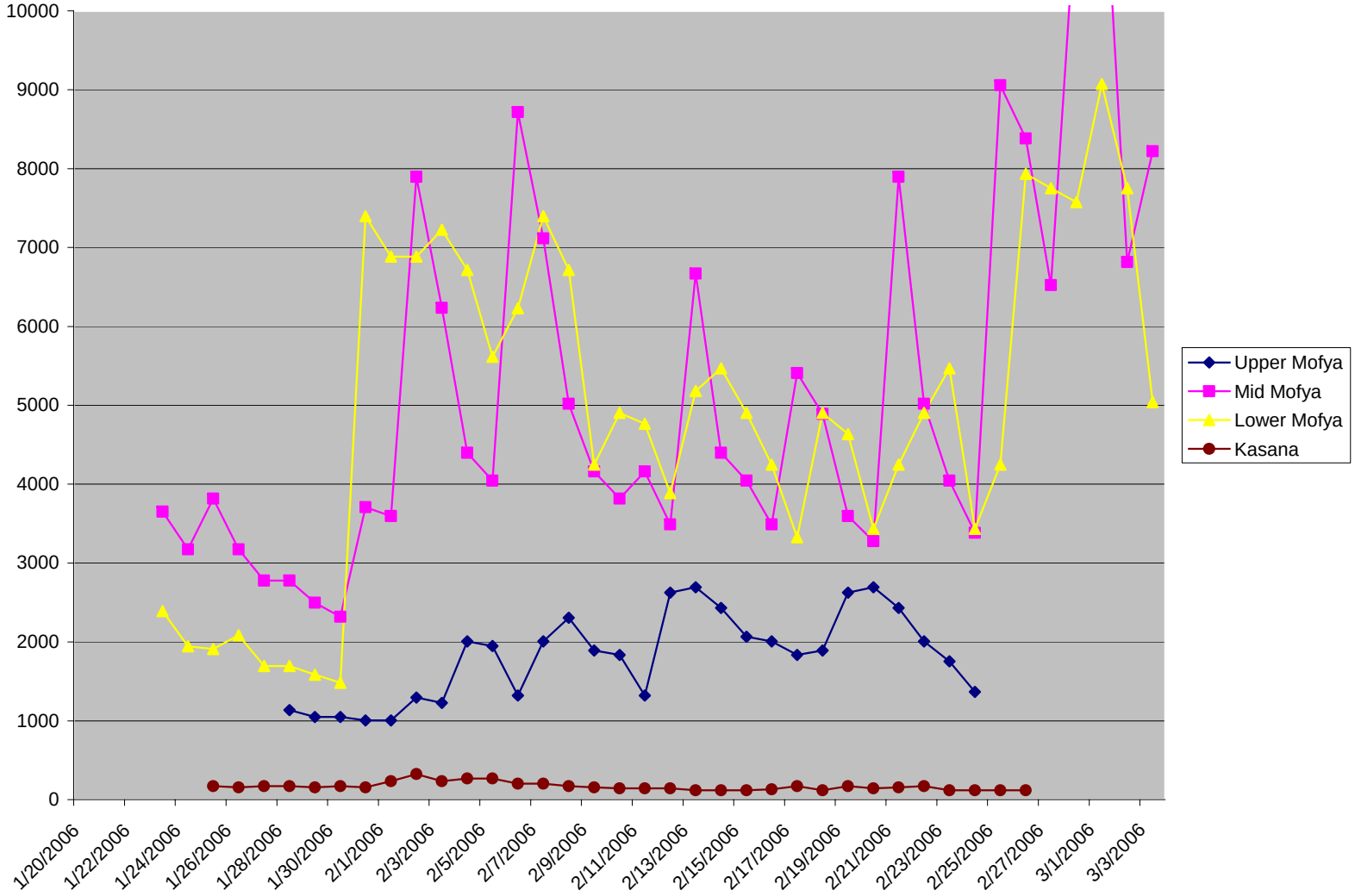


Figure 3 Measured Flow Data for Mofia



APPENDIX B2.11-VI

SURFACE WATER HYDROLOGY

AGRICULTURE CATCHMENTS RESEARCH

UNIT (ACRU) MODELING

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1 AGRICULTURAL CATCHMENTS RESEARCH UNIT (ACRU) MODELING

1.1 INTRODUCTION

Stream flow information for the rivers that flow through the Regional Study Area (RSA) is required to understand the flow in the river systems that flow through the RSA. An understanding of the flow in these river systems will be used to identify and quantify the potential impact of the proposed mine on these rivers. These potential impacts can be used to inform decision-making processes regarding the location of infrastructure and processes that will occur on the mine.

Due to limited stream flow data in the RSA, a modeling approach was followed to simulate stream flow in the RSA. Daily time-step modeling was used to estimate the stream flows during the both the dry and wet periods. Daily timestep modeling was preferred to monthly timestep modeling because monthly timestep modeling smoothes out flow spikes which generally increase base flows. Since impacts are most noticeable under baseflow conditions, this was viewed as an important consideration. Monthly timestep modeling also lacks the resolution to incorporate the impacts of isolated and infrequent incidents such as potential spills from storm water dams. This would detract from the impact assessment.

The Agricultural Catchments Research Unit (ACRU) model (Schulze 1995) was selected to simulate daily stream flows for the Dipeta and Mofia catchments in the RSA. Version 3.27 of ACRU was applied. The ACRU model has been verified on data from Southern Africa, North America and Europe. The model is used extensively in decision-making in Southern Africa and has been applied internationally in hydrological design and the simulation of water resources and research. Countries where the model has been applied include Botswana, Chile, Germany, Lesotho, Mozambique, Namibia, Swaziland, South Africa, the United States and Zimbabwe.

The model is well documented, and is maintained by a team at the University of Kwa-Zulu Natal for user support and ongoing model development through major funding primarily from the Water Research Commission in South Africa. ACRU also has the advantage of allowing for several levels of information availability. Detailed information is often not available, especially in Africa, and the user can then resort to the "experience" that has been built into ACRU by way of default values and pre-programed information.

1.2 OVERVIEW OF THE ACRU MODEL

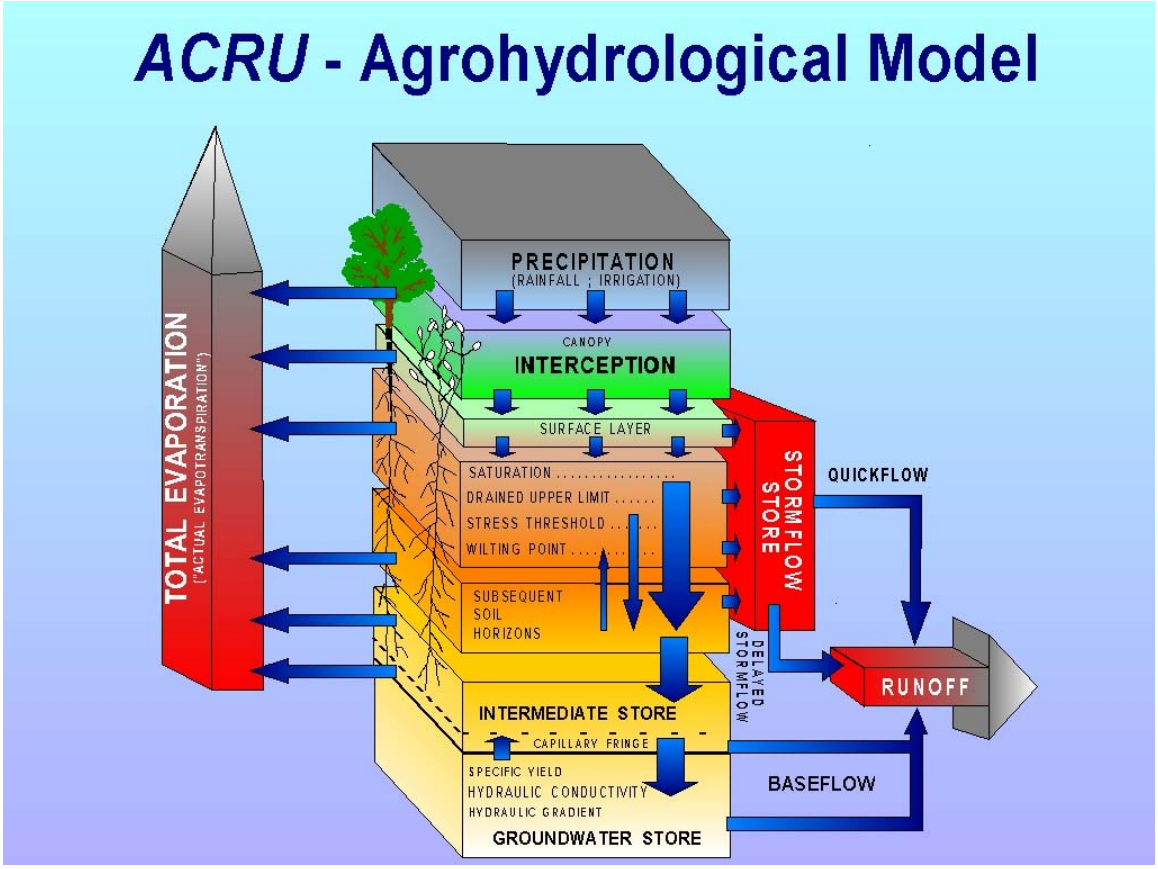
The ACRU model originated from a catchment study that was done in Natal Drakensberg, South Africa, in the early 1970s. ACRU is a physical conceptual model and not a parameter fitting or optimizing model. Variables are estimated from physical characteristics of the catchment. The ACRU model revolves around daily multi-layer soil water budgeting and the model has been developed into a total evaporation model. The general structure of the model is shown in Figure 1. The model can operate as a point model, as a lumped small catchments model, or on large (thousands of square kilometers) catchments.

ACRU operates in conjunction with the interactive ACRU Menubuilder and Outputbuilder and the associated ACRU Input Utilities. These are user interfaces to help prepare input data and information. The input files are flat ASCII text files with predefined formatting. The user interfaces essentially shields the user from the delicate formatting that is required in the input files. The Menubuilder contains alternative decision paths with a help facility, built-in default values as well as warning and error messages. The ACRU Output Utilities enable the user to print out, and to analyze the simulated results. The ACRU user manual (Smithers and Schulze 1995) and theoretical manual (Schulze 1995) can be downloaded from the ACRU homepage at http://www.beeh.unp.ac.za/acru/ for more information.

1.3 CATCHMENT DELIMITATION

The Dipeta and Mofia catchments were delimited on the basis of stream flow gauging stations in order for the simulated stream flows to be compared to observed data. The five meter contour data was used to define the catchments and catchment boundaries. The Mofia and Konka river catchments extended beyond the extents of the five meter contour data. The contour data on the Russian topographic maps was used to define the catchments and catchment boundaries beyond the extents of the five meter contour data. The Russian topographic maps have a contour interval of 40 meters. As a result, the catchment delineation in the Konka and Mofia river catchments is less accurate than the Dipeta catchments. The impacts of the reduced accuracy in the Konka and Mofia river catchments, on the modeling results, are negligible and can be ignored.

Figure 1 General Structure of the ACRU Agrohydrological Modeling System (Schulze 1995).



The subcatchment configurations for the Dipeta River and Mofia River are shown in Figure 2 and respectively. Stream flow was predicted for three tributaries that originate in the foothills of Kwatebala Hill and flow away from Kwatebala Hill towards the Mofia and Dipeta rivers. These tributaries, namely the Sokalwela, Shimpidi and Kasana rivers, may be impacted by mining operations at Kwatebala Hill. Any potential impacts on these three tributaries will be defined and quantified in the impact assessment of the environmental and social impact assessment (ESIA).

1.4 PREPARATION OF DATA INPUT FILES FOR ACRU MODEL

The ACRU model requires the following input:

- An input file containing hydrometeorological data.
- An input file with information pertaining to catchment characteristics such as location, soils, land cover and evaporation.

Figure 2 **Dipeta River Catchment Configuration.**

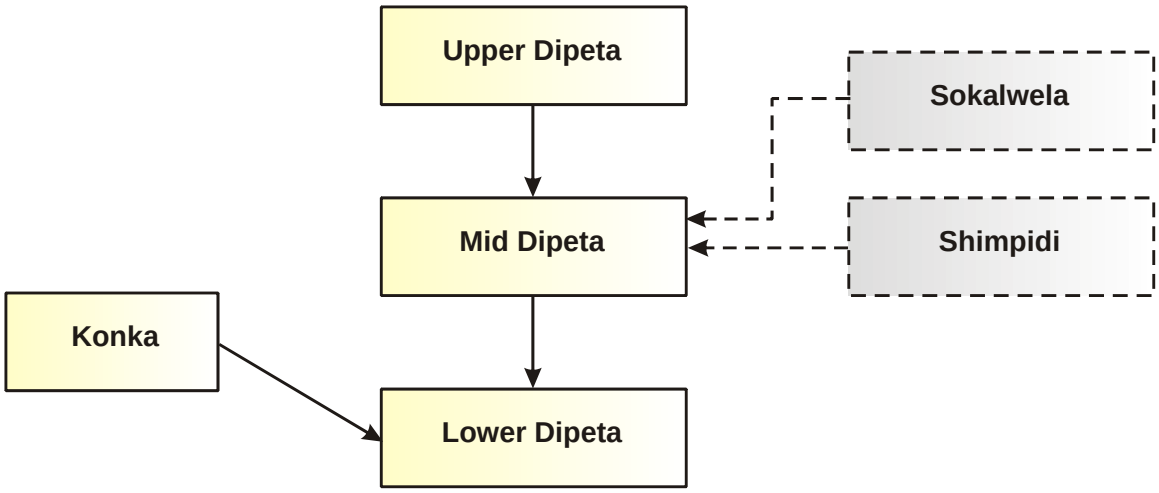
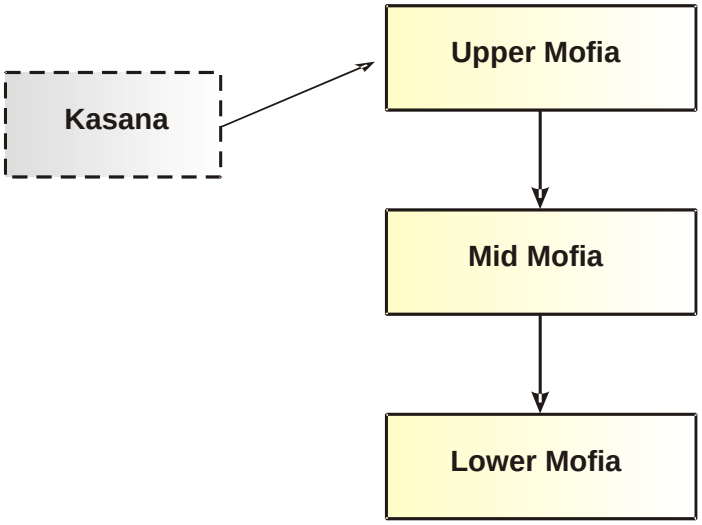


Figure 3 **Mofia River Catchment Configuration.**



- A file to indicate to the model which variables are to be stored for subsequent output and analysis.

This input data contains all of the assumptions and measured values used in the modeling. The preparation of this input data is therefore discussed in detail in the sections below.

1.5 METEOROLOGICAL DATA

Daily rainfall is the driving input variable to the ACRU model. It is important that the rainfall is representative both of the catchment and the period being analyzed. The driver station approach was applied where a rain gauge is selected to drive the hydrological response of a subcatchment.

At the time of modeling, the rain gauge at the Lukotola village mission was the preferred rain gauge for the modeling exercise. The data from the gauge at the TFM camp is incomplete. A daily rainfall file was prepared from the data recorded at the Lukotola rain gauge for ACRU (Attachment 1). The recorded rainfall data at the Lukotola rain gauge is summarized in Table 1 and Figure 4.

Table 1 Information on the Recorded Rainfall Data at the Lukotola Rain Gauge

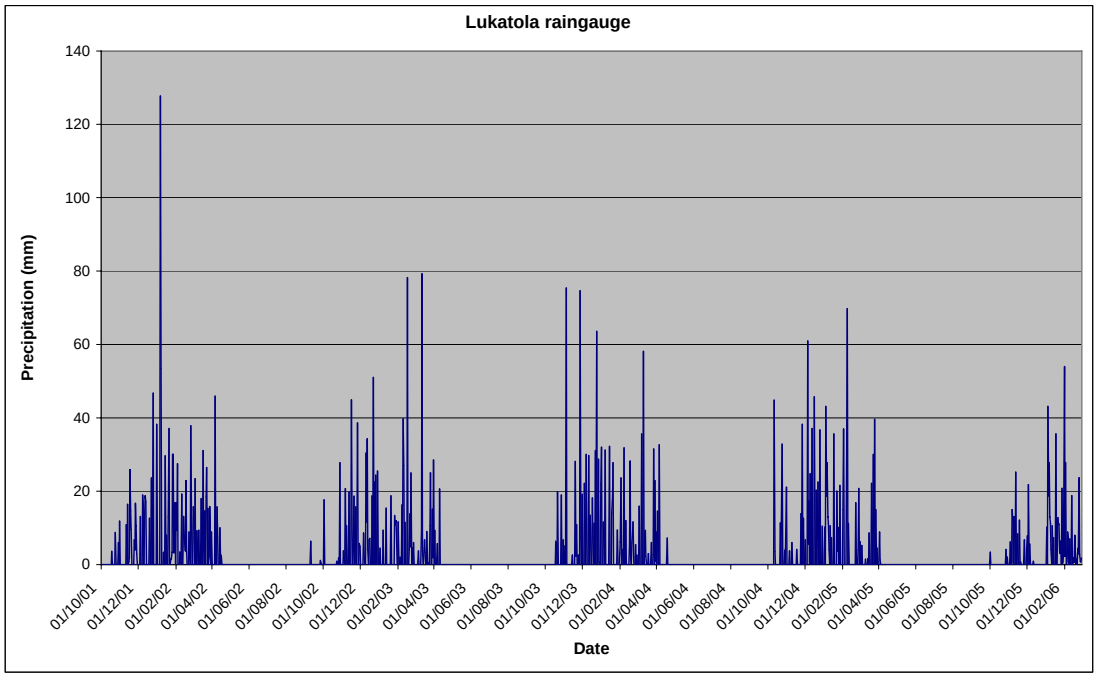
Station Altitude (mamsl)[a]	MAP[b] (mm)[c]	Record period			Missing Data (days)	% of Record With Data
		Start	End	Years		
1,160	1,160	Oct 01	Feb 06	5.5	3	99.8

(a) mamsl = meters above mean sea level.
(b) MAP = mean annual precipitation.
(c) mm = millimeters.

The record length of the Lukotola rain gauge is about a third of the ideal minimum rainfall record required for daily hydrological modeling. The ideal record length is about 15 years or more, for regions with a mean annual precipitation (MAP) of about 1,100 millimeters (Schulze et al 1995).

Due to the localized nature of most of the rainfall, the single rain gauge (or even all three rain gauges) will not accurately represent the spatial distribution of daily rainfall over the catchments. An inherent degree of uncertainty would result in the use of ACRU in the Dipeta and Mofia catchments. However, in the context of what the results will be used for, this uncertainty is acceptable and, if managed appropriately, will not affect the impact assessments that will be based on the results of the modeling.

Figure 4 Time Series of Recorded Rainfall at the Lukotola Rain Gauge.



The uncertainty will come in the form of a bias towards the characteristics of a particular area of a catchment or an isolated weather event not experienced by the whole catchment. The approach of using the Lukotola rain gauge as the only driver station for the subcatchments is not ideal due to the short daily rainfall record length and that the spatial distribution of the rainfall over the subcatchments is not accounted for. However, under the circumstances and in the context of the modeling, this can be managed. The additional modeling that will be done for the ESIA will partially reduce the level of uncertainty.

In the ACRU model reference potential evaporation (E_r) may be estimated by several equations from evaporation pan data, depending on the availability of input information. All methods of estimating the daily unscreened A-pan equivalent E_r, be they from monthly or daily data, by direct or surrogate methods, are converted in ACRU to the daily unscreened A-pan equivalent within the various E_r routines contained in the model. Available climate data recorded at the TFM camp from 1997 to 2004 (Section B2.7) were input into ACRU. No evaporation data was available for the TFM camp. Evaporation data from Solwezi was used as a substitute. This was the best available data that was suitable for use in ACRU. The climate input data are summarized in Table 2. The option was invoked which the expert system on E_r decided which method to use to calculate daily unscreened A-pan equivalent from the available input climate data.

Table 2 Climate Data Recorded at the TFM Camp Used as Input to the ACRU Model

Month	Monthly Means of Daily Maximum Temperature (ºC)[a]	Monthly Means of Daily Minimum Temperature (ºC)	Monthly Totals of A-Pan Equivalent Evaporation (mm/month)	Monthly Means of Daily Average Relative Humidity (%)
January	23.1	18.2	137	91
February	23.6	18.2	131	90
March	23.1	18.2	153	92
April	23.3	16.5	169	87
May	21.6	15.1	179	77
June	27.8	9.3	171	69
July	23.9	9.8	194	63
August	25.8	17.2	238	53
September	31.6	19.7	268	52
October	28.3	18.1	247	64
November	27.4	17.3	197	85
December	23.0	17.0	151	91

[a] °C = degrees Celcius.

1.6 CATCHMENT INFORMATION

An input file with information pertaining to location and catchment information, catchment soils information, and catchment land cover information is required for ACRU.

Locational and General Catchment Information

The area and average altitude of the subcatchments, and the latitude and longitude of the centroid of the subcatchments were determined from available digital contour data, using an ARC-GIS package. The location and general catchment information are summarized in Table 3.

Soils Information

The ACRU model requires hydrological relevant soils information on horizon thicknesses, soil water retention and redistribution constants. Soils inputs are critical to the model as they affect the rate at which the catchment “wets up” and “dries out” at the beginning and end of the rainy season. In addition to this, the soils input data determines the way catchments respond to storm events and will determine both wet and dry season base flows in the rivers. After rainfall, the soils information is the second-most important input.

Table 3 Locational and General Catchment Information Input for the ACRU Model

Subcatchment	Area of subcatchment[(a)] (km^2)	Elevation (mamsl)[(b)]	Latitude[(c)] (degree minutes)	Longitude[(c)] (degree minutes)
upper Dipeta	8.82	1,448	10 63	26 23
Sokalwela	7.72	1,323	10 58	26 17
Shimpidi	12.01	1,388	10 58	26 20
mid Dipeta	97.51	1,370	10 65	26 25
Konka	82.02	1,238	10 60	26 38
lower Dipeta	54.79	1,287	10 67	26 27
upper Mofia	161.20	1,468	10 52	26 10
Kasana	10.04	1,151	10 52	26 28
upper Dipeta	59.95	1,291	10 50	26 18
Sokalwela	168.11	1,151	10 52	26 28

(a) These are incremental catchment areas.
(b) mamsl = meters above mean sea level.
(c) ACRU requires latitude and longitude data in degrees and minutes format.

The soils map produced by Golder for the area was used (Section B2.4). The characteristics of the soil map units are summarized in Table 4. More detailed soils information was also collected from modal soil profiles (see Soil Baseline Appendix B2.4-III). The areas of the Dipeta and Mofia catchments are much larger than the area for which the soils were mapped since the scope of the hydrology and soils studies differed. A hillshade map for the Dipeta and Mofia catchments upstream of Fungurume was used, since detailed digital contour data was not available over the total area of the catchments. A hillshade map provides a graphical interpretation of land form from coarse contour data. Four types of terrain were demarcated from the hillshade map; hilly terrain, rolling and undulating terrain, gently undulating terrain, and nearly level terrain along river valleys and floodplains. The map units of the soils map were extrapolated to the catchment areas by linking a terrain type with a soil map unit (Table 5).

The “inadequate soils information option” in the model was used since the required hydrological relevant soils information was inadequate over the spatial coverage of the Dipeta and Mofia river catchments. For the “inadequate information option”, the minimum information required was an estimate of the average depth of the soils in the subcatchments and the texture classes of the soils. The percentages, by area, of the terrain types were estimated for each subcatchment. The spatial coverage (percent) of the horizon depths and texture classes for the soils in the subcatchments were determined from the estimated terrain type coverage and soil map units.

Table 4 Characteristics of the Soil Map Units.

Map Unit	Soil Depth (m)[a]	Drainage	Dominant Textures	Terrain	Location
1	> 2.00	well	clay loam to loam	gently undulating	found in the "growth area" east of Fungurume
2	> 2.00	well to moderately well	clay loam to loam	undulating	found throughout the Local Study Area (LSA) on undulating terrain
3	0.80 - 1.50 on well-weathered saprolite	well to moderately well	clay loam to loam	undulating and rolling	found throughout the LSA
4	> 1.50	imperfect to moderately well	clay loam, silt loam and loam	nearly level to very gently undulating	found along watercourses and near the alternate proposed water dam
5	0.40 - 0.80 on weathered and competent bedrock	well	loam	moderate sloping land	found along slopes of proposed water dam
6	0.00 - 0.40 on competent copper-rich bedrock	well to rapid	sandy loam, loam, sandy clay loam	gentle to steep slopes	Goma and Kwatebala Hills and Kaviwafwaulu
7	anthropogenic soils	n/a[b]	n/a	n/a	disturbed areas

[a] m = meters.

[b] n/a = not applicable.

Table 5 Linkage Between Terrain Type and Soils

Terrain Type	Soil Map Unit(s)[a]	Input Data to ACRU	
		Soil Depth	Dominant Texture
hilly	6	0.40	loam
rolling and undulating	3	1.50	clay loam
gently undulating	1 and 2	2.00	clay loam
nearly level terrain along river valleys	4	1.50	silty clay loam

[a] From Appendix B2.4-III.

The ACRU Utilities, which contains a routine for determining a weighted average of the required soils information, was used to input soils information into ACRU. In this routine, the amount of different soil groupings, their corresponding soil texture class, horizon thickness class and catchment coverage (percent) were specified for the subcatchments (Attachment 2). Pre-programmed default values were used in the ACRU Utilities to calculate the hydrological relevant soils information on horizon thicknesses, and soil water retention and redistribution constants for the subcatchments.

Land Cover Information

In its simulations ACRU is sensitive to seasonal above-ground and below-ground vegetation/land cover changes within a year, and requires monthly values on crop coefficients, leaf area index, interception loss and the fraction of the effective root system in the topsoil. A modeling option was selected to use programmed monthly default land cover values for the variety of land covers in the subcatchments. The site is dominated by an arable grassland matrix, interspersed with both small and large patches of closed and open miombo woodland grading into savanna type vegetation. Subsistence farming accounts for the vast majority of agriculture which includes maize and beans as the main crops.

Five land covers were identified in the Dipeta and Mofia river catchments for the hydrological modeling, namely woodland, grassland, copper-cobalt flora, subsistence mixed crops with maize as the main crop, and settlements. The identified land covers were related to a specific land cover listed in the ACRU model on the basis of the woodlands, grasslands and crops in the RSA, and a region with a comparable rainfall, climate and soil depths. The Zululand region (eastern regions of South Africa) has a subtropical climate with an annual rainfall of 1,000 to 1,100 millimeters, and includes areas with deeply weathered soils (> two meters deep) and similar vegetation. Table 6 summarizes the identified land covers in the subcatchments with its related crop/land cover listed in ACRU.

Table 6 Land Covers Identified in the Subcatchments and Related Land Cover Listed in ACRU Model

Subcatchment Land Cover	Land Cover Listed in ACRU	
	Number	Description
miombo woodland	2080101	indigenous forest – Zululand
grassland	2030307	Cymbopogon-Themeda veld
subsistence mixed crops with maize as the main crop	3040101	mixed crops – Mgeni region (maize / subsistence)

The subcatchments of the Dipeta and Mofia rivers upstream of Fungurume were plotted on the QuickBird satellite imagery. The percentages, by area, of the identified land covers were estimated for each subcatchment (Attachment 3). The northern half of the Mofia river catchment was not included on the QuickBird satellite imagery. A habitat distribution map in the TFM area (Section B3.1) was used to extrapolate the land cover information from the QuickBird imagery to the northern portion of the Mofia river catchment on the basis of the demarcated land cover. The ACRU Utilities, which contains a routine for determining a weighted average of the required land cover information, was used to input land cover information into ACRU. In this routine, the amount of land cover and their

corresponding catchment coverage (percent) were specified for the subcatchments (Attachment 3). Pre-programmed default values were used in the ACRU Utilities to calculate the hydrological relevant land cover information for the subcatchments.

1.6.1 Stream Flow Data

Flow depths were measured in various streams in the Dipeta and Mofia river catchments to compare simulated stream flow against measured stream flow. Information on the recorded stream flow is summarized in Table 7. Rating curves for the various stream flow measuring structures and sections were determined to calculate stream flow from observed flow depths. The rating curves for the surveyed stream cross sections were calculated using the Mannings equation. The short stream flow record length is not ideal for model verification and calibration. Additional modeling is planned, utilizing an additional 60 days of flow monitoring data, in order to verify the results.

Table 7 Information on the Recorded Stream Flow Depth Data

Gauging Station		Record Period			Missing Data (days)	% of Record With Data
Subcatchment	Type	Start	End	Days		
upper Dipeta	rectangular section	23/01/06	31/03/06	68	2	97
Sokalwela	surveyed stream cross section	22/01/06	22/03/06	60	1	98
Shimpidi	rectangular section	25/01/06	28/03/06	63	0	100
mid Dipeta	weir[(a)]	25/01/06	25/03/06	60	3[(b)]	95
Konka	weir[(a)]	21/01/06	24/02/06	35[(c)]	5	86
lower Dipeta	surveyed stream cross section	23/01/06	25/03/06	62	0	100
upper Mofia	surveyed stream cross section	26/01/06	22/02/06	28[(c)]	0	100
Kasana	surveyed stream cross section	23/01/06	24/02/06	33[(c)]	0	100
mid Mofia	surveyed stream cross section	23/01/06	31/03/06	68	0	100
lower Mofia	control section	23/01/06	29/03/06	66	0	100

(a) The weir has been undercut in places. Some water flows under weir.

(b) The gauge plate may have been stolen, but was replaced within three days.

(c) Data for March 2006 has been recorded but was not available at the time of modeling.

1.7 CALIBRATION OF ACRU MODEL

While ACRU has not been developed as a parameter optimizing model to be calibrated until the simulated stream flow values mimic the observed values closely,

a certain amount of calibration is inevitable in hydrological modeling (Schulze and Smithers 1995). After care was taken that all meteorological and catchment input values are of the best quality possible, especially those that are sensitive, ACRU was calibrated by adjusting the variables controlling the generation and timing of stream flow.

The stream flow variables were initially adjusted to fit a long-term stream flow-rainfall relationship. This relationship provides a first approximation of the order of magnitude for the observed and simulated mean annual stream flows in Southern Africa for catchments under natural conditions (Schulze and Smithers 1995).

The stream flow-rainfall relationships in many regions in Southern Africa have been extensively studied using ACRU and are relatively well understood.

The RSA was therefore compared to a similar region in order to use existing experience and understanding about the stream flow-rainfall relationship. The relationship was considered as guide since the runoff response may be different due to the deeply weathered soils, and differences in catchment areas and land cover between the subcatchments. The Zululand region in South Africa was selected as the region representing the RSA due to comparable MAP, vegetation, areas with deeply weathered materials (< two meters deep), and a subtropical climate. According to Schulze and Smithers (1995), the long-term stream flow is about 14 percent of the long-term annual rainfall for the Zululand region.

Table 8 summarizes the simulated mean annual runoff (MAR) of the subcatchments as a percentage of the MAP for the period October 1, 2001 to September 30, 2005. The variables that were adjusted from default values are (model parameter names are included in brackets):

- The effective (critical) depth of the soil from which stormflow generation takes place (ACRU parameter SMDDEP).
- Fraction of “saturated” soil water to be redistributed daily from the topsoil into the subsoil (ACRU parameter ABRESP).
- Fraction of “saturated” soil water to be redistributed daily from the subsoil into the intermediate/groundwater store (ACRU parameter BFRESP).
- Coefficient of initial abstraction (ACRU parameter COIAM).
- And to a lesser extent the coefficient of baseflow response (ACRU parameter COFRU).

Table 8 Percentage of Simulated Annual Stream Flow of the MAP

Subcatchment	Catchment Area Above Gauging Station (km^2)	Simulated MAR-MAP (%)
upper Dipeta	8.82	19.1
Sokalwela	7.72	13.5
Shimpidi	12.01	19.5
mid Dipeta	106.3	16.4
Konka	82.02	18.9
lower Dipeta	233.2	22.8
upper Mofia	161.2	22.2
Kasana	10.33	22.2
mid Mofia	221.6	23.6
lower Mofia	389.3	24.1

Note: These areas are cumulative areas.

Values for ABRESP and BFRESP were taken from the values calculated by the ACRU Utilities. The default value for SMDDEP was adjusted for high rainfall areas and deeply weathered soils. The coefficient of initial abstraction (COIAM) calculated from the area weighted land covers of the subcatchment (Attachment 3) and recommended "first run" monthly values for general land covers summarized in Table 9. COIAM is used to estimate the rainfall abstracted by interception, surface storage and infiltration before stormflow begins.

Table 9 Monthly Coefficient of Initial Abstraction for General Land Covers

	Coefficient of Initial Abstraction (COIAM)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
natural bush	0.20	0.20	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.20	0.20
natural veld	0.15	0.15	0.15	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.20	0.15
subsistence agriculture	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.35	0.25

The MAR to MAP ratio is in general higher than the suggested relationship for the Zululand region. The relationship is also higher for larger catchment areas and for the subcatchments in the Mofia catchment. Generally, the recharge to discharge ratios of the catchments decreases as the order of the river increases. As an example, a first order stream (headwater stream) will have high infiltration and therefore high recharge. The shallow groundwater generally does not contribute to stream flow in the headwaters and the discharge of groundwater is therefore low. A fifth order stream, for example, may experience the same high recharge. However, groundwater contributions from both the shallow groundwater system and the deep groundwater system (through springs) will be

significant. The discharge to these rivers, from groundwater, is therefore high relative to a first order stream. The ratio of this recharge to discharge would be expected to reduce as the stream order increases.

Although the stream flow-rainfall relationship is generally higher than what has been recorded in the Zululand region, the variables were not adjusted further to keep the adjustments physically realistic and hydrologically justifiable. Furthermore, the rainfall record length is too short to include enough dry and wet periods for a long-term stream flow-rainfall relationship. The relationships presented in Table 8 compares to relationships found for high-rainfall mountainous areas in Southern Africa, so is not unrealistic.

Following on the initial adjustments of stream flow variables to fit the long-term stream flow-rainfall relationship, daily time series simulated flow data for the period October 1 2001 to September 30 2005 was plotted against estimated baseflow levels during the wet and dry seasons (Attachment 4). Dry season baseflows in the Dipeta River are based on the work done by SRK (SRK 1973). Other baseflows are based on the flow estimates observed in December 2005. The estimated baseflow levels used for calibration are summarized in Table 10.

Table 10 Estimated Baseflows Used for Calibration

Subcatchment	Baseflows (l/s)[(a)]	
	Dry Season	Wet Season
upper Dipeta	2-5	100
Sokalwela	15	100
Shimpidi	15	150
mid Dipeta	75	600
Konka	100	750
lower Dipeta	500	3000
upper Mofia	350	1000
Kasana	15	150
mid Mofia	500	2500
lower Mofia	1000	3500

[(a)] l/s = liters per second.

The estimated baseflow levels for the dry season were satisfactory simulated by ACRU for all the subcatchments except for the Sokalwela where the baseflows are under-stimulated during the drier years. The Sokalwela River is fed by springs which may explain the under-simulation.

It should be noted that no dry season flow measurements or estimates have been made. The December 2005 site visit would probably have already been in the

"wetting up" phase of the catchments. We would expect dry-season base-flows to be less than the flows that were observed in December 2005. Wet season base flows were based on single flow measurements taken during January 2006, and the measured flow depths at the ten gauging stations. These too are estimates based on limited data.

Adjustments were made in the coefficient of baseflow response (COFRU) to adjust the baseflows that were simulated generally too high or too low. Adjusted COFRU values varied between 0.008 and 0.009 for the smaller catchments (>15 square kilometers) and 0.006 and 0.007 for the larger catchments. The value for SMDDEP was adjusted to 0.50 in order to match the simulated baseflows with the estimated baseflows. The default value of 0.30 was used for the variable on stormflow response fraction (ACRU parameter QFRESP).

The estimated baseflow levels for the dry season were satisfactory simulated by ACRU for the all the subcatchments except for the Sokalwela where the baseflows are under-simulated during the drier years. The Sokalwela River is fed by springs which may explain the under-simulation.

The estimated baseflow levels for the wet season were more difficult to predict since the baseflow levels were under-simulated during the wetting-up phase of the rainy season. The estimated wet season baseflow levels were also under-simulated in all the subcatchments during the drier 2002/2003 season. A comparison of simulated wet season baseflows after the wetting-up phase and the estimated wet season baseflow levels are summarized in Table 11. The contribution of spring flows to stream flow in the Sokalwela, Shimpidi and possibly Konka river subcatchments is not predicted by ACRU. We would therefore expect ACRU to under simulate the baseflows in these rivers. We are not aware of any springs that are present in Konka river catchment, as the groundwater study did not investigate the Konka River. However, the presence of springs in the Konka river catchment is plausible and can explain the under-simulation of the baseflows.

Phase shifts in the baseflows, i.e., if the baseflows occurred too early or too late, could not be verified since the observed stream flow data did not include a wetting-up or drying-out phase. The current stream flow observations will be continued until the end of 2006 to include stream flow observations during the drying-out phase of the current wet season, the dry season and the wetting-up phase of the following wet season in order to verify shifts in the simulated baseflows.

Table 11 Verification of the Calibrated ACRU Model for the Wet Season Baseflows After the Wetting-Up Phase

Subcatchment	Wet Season Baseflow (l/s)[(a)]		Comment on Simulated Baseflow
	Estimated Level	Simulated Range	
upper Dipeta	100	85-110	satisfactory
Sokalwela	100	35-55	under-simulated
Shimpidi	150	90-110	under-simulated
mid Dipeta	600	640-710	over-simulated
Konka	750	540-660	under-simulated
lower Dipeta	3,000	2,500-3,300	satisfactory
upper Mofia	1,000	900-1,200	satisfactory
Kasana	150	115-170	satisfactory
mid Mofia	2,500	2,100-2,700	satisfactory
lower Mofia	3,500	2,800-4,200	satisfactory

[(a)] l/s = liter per second

The observed stream flow record was too short to apply statistical measures, i.e., regression and comparative statistics, 1:1 plots and double mass plots, for further model calibration and verification of simulated stormflows. The record length, shown in Table 7, is also too short to take account of the effect of simulated outliers and inliers which could be the effect of missing or incorrect rainfall or stream flow data, that the spatial distribution of the rainfall over the subcatchments is not effectively accounted for, inaccurate rating tables being applied at gauging stations, or that overtopping or undercutting may have occurred at the gauging structures.

However, the purpose of the ACRU modeling was to reproduce those stream flow aspects that can be used to identify and quantify any potential impacts as a result of the mining operations. Of particular importance in this regard are the dry season flows, wet season baseflows and mean annual runoff.

The input data of the calibrated ACRU model is summarized in Attachment 5.

1.8 SIMULATED STREAM FLOWS

Daily time-step modeling was used to make quantitative estimates of stream flow for the Dipeta and Mofia river systems. This will be used to identify any potential impacts as a result of the proposed mine. Virtually no stream flow data is available so a modeling approach was followed. The calibrated ACRU model was applied to predict daily stream flow for the Dipeta and Mofia rivers from October 1, 2001 to September 30, 2005 (Attachment 4). Daily flows were also

simulated for the Shimpidi, Sokalwela, Konka and Kasana catchments. The Shimpidi, Sokalwela and Kasana catchments are the catchments most likely to be impacted by the mining of Kwatebala Hill.

The results of the predicted daily average stream flow (cubic meters per second) for the subcatchments are summarized in Table 12.

Table 12 Predicted Daily Average Stream Flow

Subcatchment	Catchment Area Above Gauging Station (km^2)	Daily Average Stream Flow (l/s)[(a)]		
		Annual	Wet Season	Dry Season
upper Dipeta	8.82	63.0	97.7	28.8
Sokalwela	7.72	38.8	59.9	17.9
Shimpidi	12.01	87.2	124.6	50.5
mid Dipeta	106.3	650	979	326
Konka	82.02	579	826	335
lower Dipeta	233.2	1,972	2,799	1,158
upper Mofia	161.2	1,329	1,908	759
Kasana	10.33	85.2	122	486
mid Mofia	221.6	1,939	2,742	1,149
lower Mofia	389.3	3,481	4,893	2,092

[(a)] l/s = liters per second.

The wet season includes the period from November 1 to April 31, and the dry season extends from May 1 to October 31. October was included in the dry season since low stream flows were predicted due to the wetting-up of the catchments at the start of the rainy season. Rains generally appear to start in mid-October.

The predicted daily average flows show that higher stream flows are produced in the Mofia River system than in the Dipeta River system. The mean annual stream flow predicted at the outflow (from the RSA) of the lower Mofia catchment is almost twice as much as at the outflow (of the RSA) of the lower Dipeta catchment. The simulated daily average flows in the Sokalwela, Shimpidi and Kasana rivers are in the same order of magnitude. The simulated mean annual stream flow in the Shimpidi and Kasana are the same, whereas the Sokalwela is about half that of the Shimpidi and Kasana rivers.

The Mofia River catchment area upstream of the confluence of the Kasana River is much larger than the Dipeta River catchment area upstream of the confluences of the Sokalwela and Shimpidi rivers. This is reflected in the daily average stream flows at the mentioned confluences. The predicted daily stream flow for the mid Mofia River into which the Kasana River flows is about three times

higher than the predicted stream flow for the mid Dipeta River into which the Sokalwela and Shimpidi rivers flow.

The contribution of the Konka River towards stream flow in the lower Dipeta catchment is almost the same as from the mid Dipeta catchment. The predicted stream flow for the upper Dipeta catchment is much lower than the predicted stream flow in the upper Mofia catchment. This is due to the upper Dipeta River catchment being substantially smaller than the upper Mofia River catchment.

As a result, the dilution effect of possible poor water quality from the mining site will be higher in the Mofia River than in the Dipeta River, both in terms of the stream flows at the mentioned confluences and river systems as a whole. The dilution effect will also be lower in the Sokalwela River than in the Kasana and Shimpidi rivers due to the lower simulated stream flow in the Sokalwela River.

The dilution effect will be much higher during the wet season than the dry season since the mean daily average flows simulated for the wet season is over three times higher than the dry season. The mean daily average stream flow for the wet season comprise over 70 percent (70 to 76 percent) of the mean annual daily average stream flow.

Non-exceedance probability distributions provide an indication of the water available at the gauging sites (Attachment 6). Results from the flow duration curves are summarized in Table 13 and Table 14.

Table 13 Predicted Daily Average Stream Flow for the Wet Season

Subcatchment	Percentiles of Average Daily Stream Flow (l/s)[(a)]			
	5	25	50	95
upper Dipeta	5.5	15.5	78.9	249.5
Sokalwela	4.4	13.5	37.2	161.5
Shimpidi	17.1	32.2	92.1	298.8
mid Dipeta	90.1	209.2	716.5	2,583.7
Konka	131.6	234.1	600.2	2,002.3
lower Dipeta	467.5	968.7	2,418.5	6,109.8
upper Mofia	303.7	510.7	1,483.8	4,150.9
Kasana	19.5	32.7	95.1	266.0
mid Mofia	516.4	846.6	2,392.5	5,955.3
lower Mofia	933.3	1,577.0	4,267.6	10,563

[(a)] l/s = liters per second.

Table 14 Predicted Daily Average Stream Flow for the Dry Season

Subcatchment	Percentiles of Average Daily Stream Flow (l/s)[(a)]			
	5	25	50	95
upper Dipeta	6.3	10.9	22.1	78.7
Sokalwela	1.4	5.1	15.1	52.4
Shimpidi	15.9	27.6	41.4	108.6
mid Dipeta	57.0	125.5	256.2	858.1
Konka	112.0	191.5	279.1	895.0
lower Dipeta	456.8	668.4	962.8	2,748.7
upper Mofia	310.4	455.2	645.5	1924.5
Kasana	19.9	29.2	41.4	123.2
mid Mofia	517.6	715.0	969.2	2,745.9
lower Mofia	941.1	1,297.3	1,755.9	4,993.6

[(a)] l/s = liters per second

The results from the non-exceedance probability distributions confirm the findings from the previous discussion in that the dilution effect of possible poor water quality is higher for the Mofia River system than the Dipeta River system during both the wet and dry seasons. The predicted daily stream flow for the Shimpidi and Kasana rivers is almost the same at all the percentiles during the wet and dry seasons. The predicted daily stream flow for the Sokalwela River is much lower than the Shimpidi and Kasana rivers at the low flows (5th and 25th percentile) during the wet and dry seasons. Consequently, the Sokalwela River has a much lower dilution potential for possible poor water qualities than the Shimpidi and Kasana rivers. The low flows (5th and 25th percentile) predicted for the wet and dry seasons are of the same order of magnitude. This indicates that the predicted baseflows during a dry period and / or the wetting-up phase in the wet season can be as low as the baseflows in the dry period.

If the predicted daily stream flow time series in Attachment 4 are examined, it is clear that the baseflows for the wet seasons are as low as for the dry season during the drier 2002/2003 hydrological year, and the wetting-up phase that continue until December. This indicates that there is a possible phase shift in the predicted stream flows, i.e., wetting-up and drying-out phases occurs too late. Therefore, the current stream flow observations should be continued to include stream flow observations during the drying-out phase of the current wet season, the dry season and the wetting-up phase of the following wet season in order to verify these shifts. The predicted wet season daily average stream flow differs significantly from the dry season at the 50th and 95th percentile.

ATTACHMENT 1

DAILY RAINFALL DATA USED TO PREPARE THE RAINFALL FILE FOR AGRICULTURAL CATCHMENTS RESEARCH UNIT (*ACRU)*

Table 1 Daily Rainfall Data for ACRU Model

YEAR	MONTH	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2001	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0	8.8	0.0	0.0	0.0	0.0	6.0	0.0	11.9
2001	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.9	0.0	16.4	0.0	0.8	1.9	25.9	14.6	9.5	0.0	0.0	0.0	0.0	6.8	4.0	16.7	10.6	3.0	0.0	0.0	
2001	12	0.0	0.0	0.0	13.1	0.0	0.0	0.0	19.0	16.1	0.0	13.7	18.8	17.1	0.0	0.0	0.0	0.0	0.0	12.6	0.0	0.0	23.6	0.0	0.0	46.7	0.0	0.0	0.0	0.0	0.0	38.3
2002	1	0.0	0.0	0.0	0.0	0.0	127.8	53.4	0.0	0.0	0.0	3.4	0.0	0.0	29.6	0.0	8.0	0.0	0.0	13.1	37.1	0.0	0.0	1.5	1.5	3.4	30.0	30.0	3.2	5.6	16.9	0.0
2002	2	16.9	9.4	27.5	0.0	0.0	0.0	3.5	2.7	0.0	19.3	0.0	0.0	13.1	7.5	6.8	3.8	22.9	3.4	0.0	0.0	0.0	8.9	2.0	0.0	37.9	15.8	0.0	0.0			
2002	3	15.8	13.5	0.0	23.4	0.0	0.0	9.2	4.1	0.0	9.4	0.0	0.0	0.0	18.0	0.0	0.0	31.1	5.3	0.0	14.6	0.0	18.6	26.5	0.0	15.3	0.0	2.3	15.8	8.5	0.0	8.9
2002	4	0.0	0.0	0.0	0.0	0.0	45.9	0.0	0.0	15.8	7.5	0.0	0.0	0.0	10.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2002	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2002	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2002	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2002	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2002	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.4	0.0	0.0	0.0	
2002	10	0.0	17.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	1.9	0.0	27.8	0.0	0.0	0.0
2002	11	0.0	0.0	3.8	0.0	0.0	20.7	0.0	10.7	0.0	0.0	0.0	19.8	0.0	0.0	0.0	44.9	8.8	0.0	3.8	18.6	0.0	0.8	15.8	0.0	13.1	38.6	0.0	0.0	5.8	4.9	
2002	12	0.0	0.0	0.0	0.0	0.0	8.6	1.9	0.0	0.0	30.4	11.6	34.3	4.1	0.0	6.8	7.1	0.0	0.0	0.0	18.8	0.0	51.0	0.0	22.5	0.0	24.4	0.0	0.0	25.5	0.0	0.0
2003	1	0.0	4.5	0.0	0.0	0.0	0.0	9.4	0.0	0.0	0.0	0.0	15.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.8	0.0	0.0	0.0	0.0	0.0	13.4	10.9	12.0	9.2	0.0	0.0
2003	2	11.6	0.0	0.0	2.0	0.0	0.0	16.3	0.0	39.8	27.0	0.0	11.5	0.0	0.0	0.0	78.2	0.0	0.0	4.1	13.8	4.9	25.0	0.0	4.7	0.0	6.0	0.0	0.0			
2003	3	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	9.4	79.2	3.8	0.0	2.6	6.8	3.3	0.0	0.0	9.0	0.0	0.5	0.0	0.0	10.7	25.1	0.0	0.0	15.1	1.9	28.5
2003	4	0.0	9.3	0.0	0.0	0.0	5.7	0.0	0.0	0.0	20.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2003	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2003	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2003	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	5.2	0.0	19.9	0.0	0.0	0.0	0.0	0.0	19.0	0.0	0.0	6.8	0.0
2003	11	0.0	5.1	0.0	75.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	28.1	2.3	10.9	0.0	0.0	2.6	0.0	0.0	74.6	7.4	0.0	19.2	
2003	12	0.0	0.0	0.0	22.1	0.0	7.8	30.0	0.0	0.0	0.0	29.8	0.0	13.5	10.4	0.0	0.0	18.2	7.5	0.0	11.3	0.0	31.1	0.0	63.6	7.5	0.0	28.8	0.8	0.0	0.0	22.0
2004	1	32.0	0.0	0.0	11.6	7.1	0.0	31.2	0.0	0.0	0.0	0.0	0.0	0.0	32.3	0.0	0.0	0.0	14.3	18.8	27.8	0.0	0.0	0.0	0.0	0.0	0.0	9.4	0.0	0.0	0.0	3.0
2004	2	6.1	23.6	0.0	4.1	3.7	0.0	31.9	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	5.6	28.2	1.9	0.0	6.0	8.6	11.6	0.0	0.0	0.0	5.4	0.0	2.6	0.0		
2004	3	0.0	0.0	15.9	0.0	0.0	0.0	35.6	0.0	0.0	58.1	0.0	7.5	9.3	2.3	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	2.8	31.5	0.0	22.9	0.9	8.9
2004	4	0.0	14.6	3.8	0.0	32.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2004	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2004	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2004	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.8	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.4	0.0	20.4	32.9	0.0	0.0	0.0	3.9	0.0	7.0	21.1
2004	11	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	13.9	0.0	38.3	0.0	12.6	0.0	1.9	
2004	12	6.8	0.0	0.0	0.0	61.0	5.6	17.3	0.0	24.8	0.0	0.0	37.1	0.0	0.0	0.0	45.8	0.0	0.0	20.3	0.0	9.8	22.5	0.0	0.0	36.8	0.0	0.0	0.0	10.4	0.0	0.0
2005	1	0.0	10.2	0.0	43.1	18.8	27.8	13.0	11.3	4.1	0.0	10.6	0.0	7.4	0.0	0.0	0.0	35.6	0.0	0.0	0.0	0.0	20.0	3.6	10.1	0.0	0.0	21.6	0.0	0.0	0.0	0.0
2005	2	15.0	37.0	0.0	0.0	0.0	0.0	29.3	69.8	0.0	11.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.9	0.0	0.0	0.0	4.0	20.8	0.0			
2005	3	6.2	0.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	1.7	0.0	8.6	0.0	0.0	0.0	22.1	0.0	14.3	30.0	0.0	39.6	0.0	15.0	0.0	4.5	0.0	0.0
2005	4	0.0	8.9	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2005	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2005	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2005	10	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0	2.0	0.0	0.0
2005	11	0.0	0.0	6.2	0.0	0.0	15.0	12.2	0.4	13.1	10.9	0.0	25.2	0.0	0.0	8.4	0.0	0.0	12.2	0.0	0.8	0.0	0.0	0.0	0.0	0.0	6.8	0.0	0.0	0.0	4.4	
2005	12	7.9	0.0	21.8	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	1	0.0	10.2	0.0	43.1	18.8	27.8	13.0	11.3	4.1	0.0	10.6	0.0	7.4	0.0	0.0	0.0	35.6	0.0	0.0	12.8	11.4	11.0	3.8	3.0	6.4	0.0	20.8	0.4	3.6	16.0	54.0
2006	2	2.2	27.8	0.0	0.8	8.8	7.6	0.2	0.0	7.0	0.0	0.0	18.8	0.0	0.4	1.8	0.6	8.0	2.8	0.2	1.4	0.2	4.4	3.0	23.6	2.8	0.8	0.8	1.8			

ATTACHMENT 2

SOIL TEXTURE CLASS, HORIZON THICKNESS CLASS AND CATCHMENT COVERAGE (PERCENT) OF THE DIFFERENT SOIL GROUPINGS SPECIFIED FOR THE VARIOUS SUBCATCHMENTS

Table 1 **Upper Dipeta**

Map Unit	Catchments Coverage %	Soil Texture Class	Horizon Thickness Class
4	5	9	1
1 and 2	60	8	1
3	25	8	1
6	10	2	3

Table 2 **Sokalwela**

Map Unit	Catchments Coverage %	Soil Texture Class	Horizon Thickness Class
4	10	9	1
1 and 2	85	8	1
3	5	8	1
6	0	2	3

Table 3 **Shimpidi**

Map Unit	Catchments Coverage %	Soil Texture Class	Horizon Thickness Class
4	5	9	1
1 and 2	70	8	1
3	20	8	1
6	5	2	3

Table 4 **Mid Dipeta**

Map Unit	Catchments Coverage %	Soil Texture Class	Horizon Thickness Class
4	7	9	1
1 and 2	83	8	1
3	7	8	1
6	3	2	3

Table 5 **Konka**

Map Unit	Catchments Coverage %	Soil Texture Class	Horizon Thickness Class
4	5	9	1
1 and 2	75	8	1
3	12	8	1
6	8	2	3

Table 6 **Lower Dipeta**

Map Unit	Catchments Coverage %	Soil Texture Class	Horizon Thickness Class
4	4	9	1
1 and 2	81	8	1
3	9	8	1
6	6	2	3

Table 7 **Upper Mofia**

Map Unit	Catchments Coverage %	Soil Texture Class	Horizon Thickness Class
4	2	9	1
1 and 2	48	8	1
3	50	8	1
6	0	2	3

Table 8 **Mid Mofia**

Map Unit	Catchments Coverage %	Soil Texture Class	Horizon Thickness Class
4	5	9	1
1 and 2	35	8	1
3	60	8	1
6	0	2	3

Table 9 **Lower Mofia**

Map Unit	Catchments Coverage %	Soil Texture Class	Horizon Thickness Class
4	5	9	1
1 and 2	40	8	1
3	55	8	1
6	0	2	3

ATTACHMENT 3

CATCHMENT COVERAGE (PERCENT) OF THE LAND COVERS SPECIFIED FOR THE VARIOUS SUBCATCHMENTS

Table 1 Catchment Covers for Various Subcatchments

Sub-catchment	Zululand Indigenous Forest CROPNO: 2080101	Cymbopogon Themeda Veld CROPNO: 2030307	Mixed Crops (Maize/Subsistence) CROPNO: 3040201
upper Dipeta	60	35	5
Sokalwela	84	12	4
Shimpidi	44	14	42
mid Dipeta	69	21	10
Konka	60	21	19
lower Dipeta	26	31	11
upper Mofia	52	37	11
Kasana	-	-	-
mid Mofia	31	47	22
lower Mofia	30	19	81

ATTACHMENT 4

COMPARISONS OF DAILY SIMULATED STREAMFLOW TIME SERIES AGAINST ESTIMATED BASEFLOW LEVELS DURING THE WET AND DRY SEASON

Figure 1 Upper Dipeta

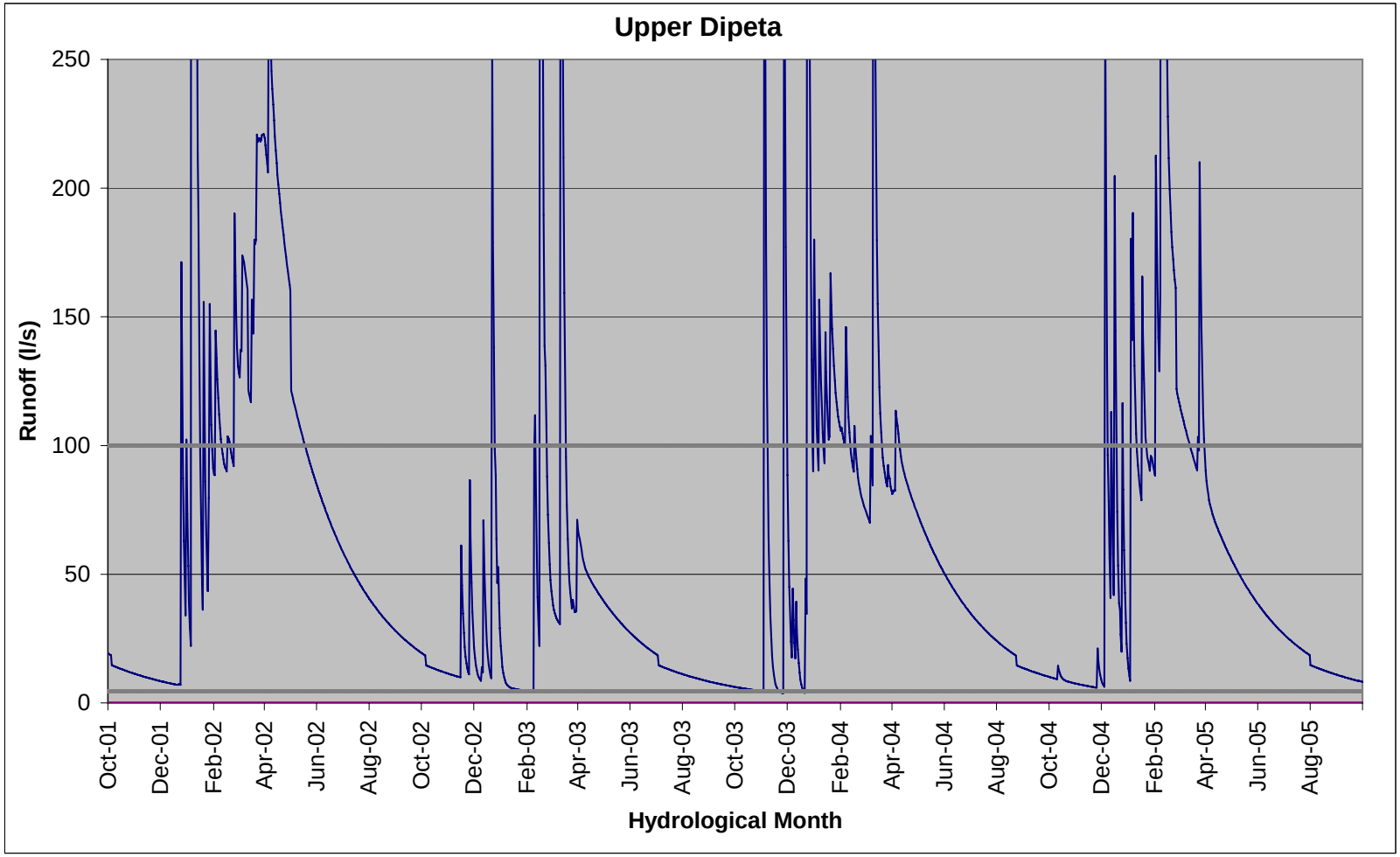


Figure 2 Sokalwela

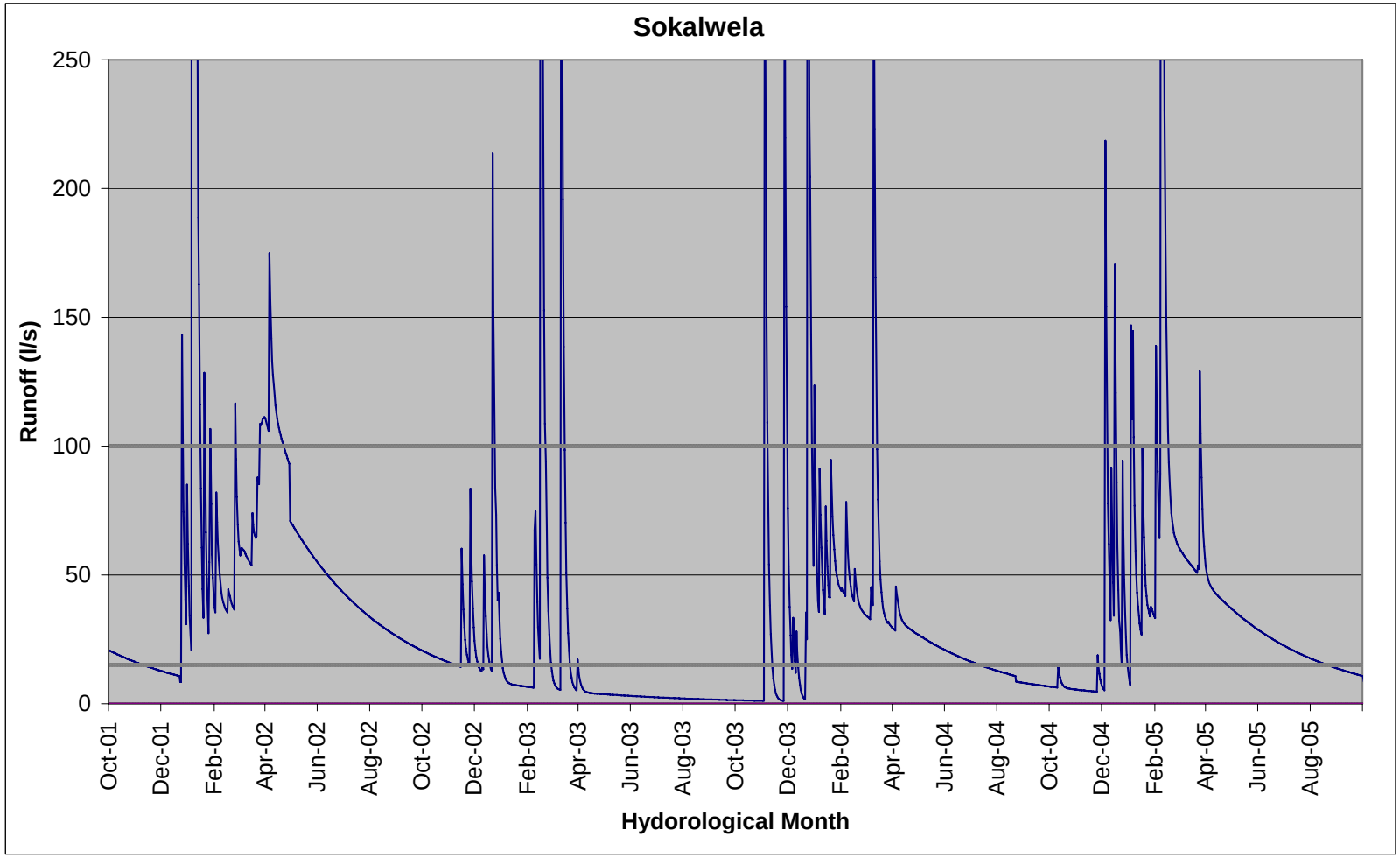


Figure 3 Shimpidi

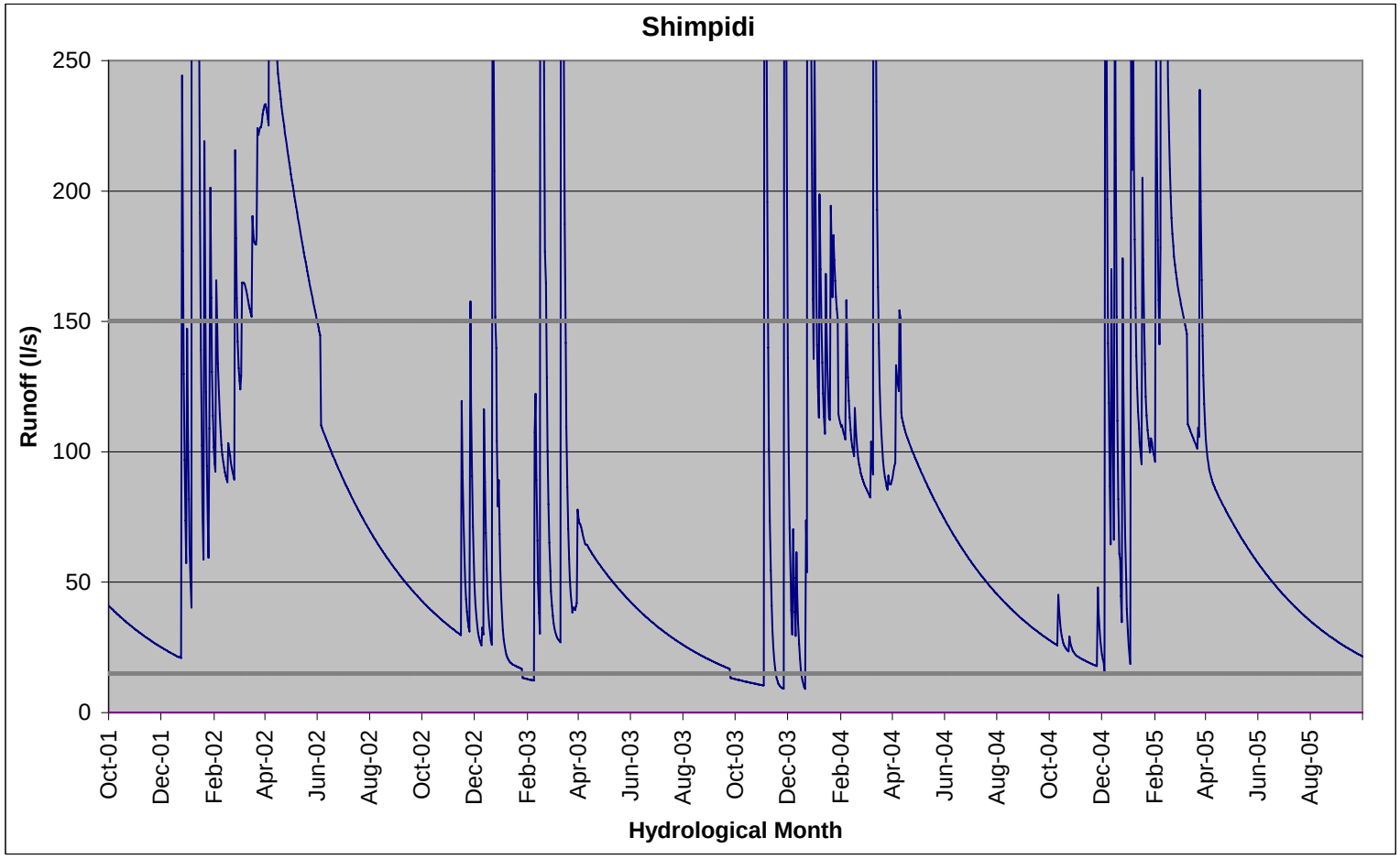


Figure 4 Mid Dipeta

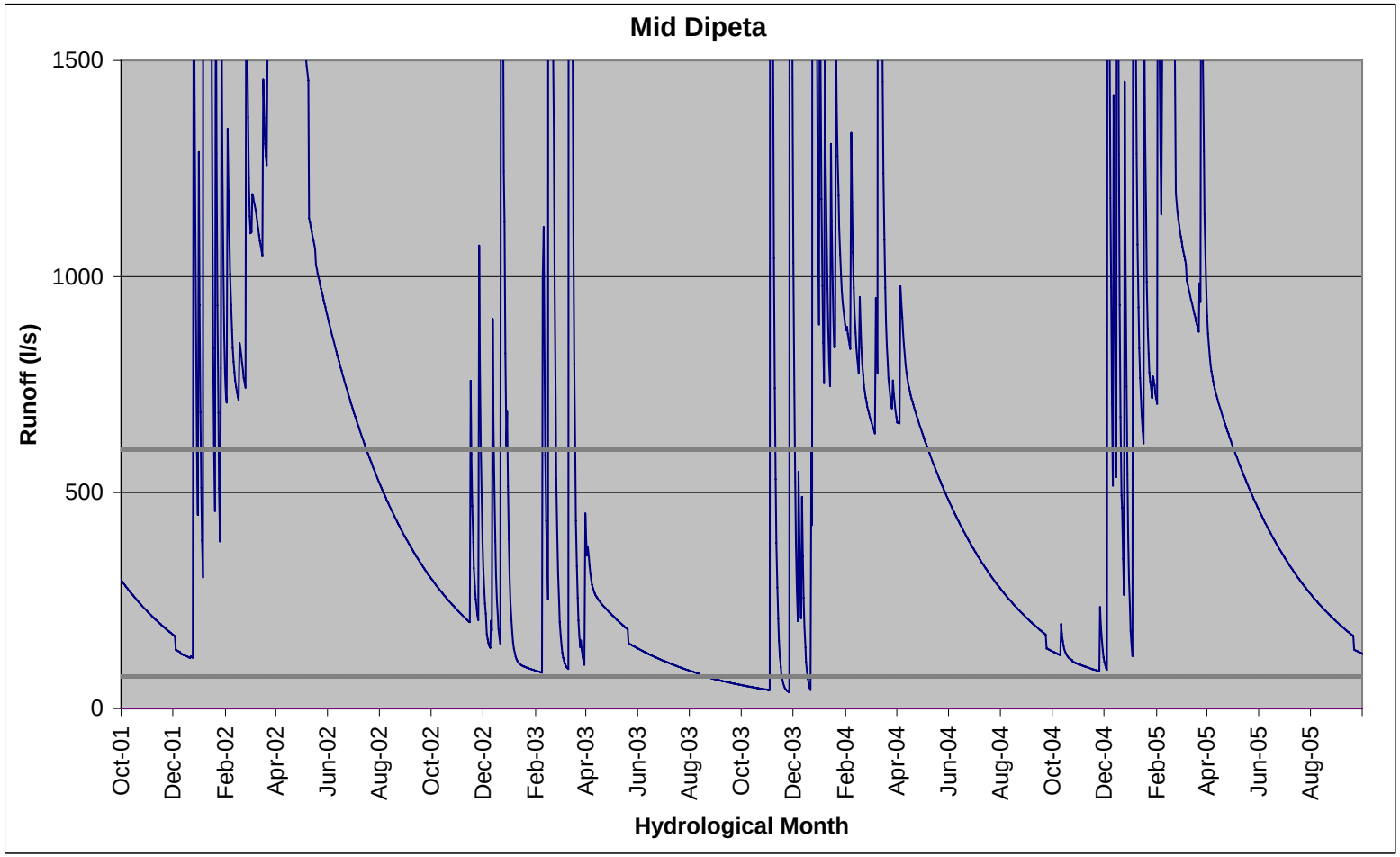


Figure 5 Konka

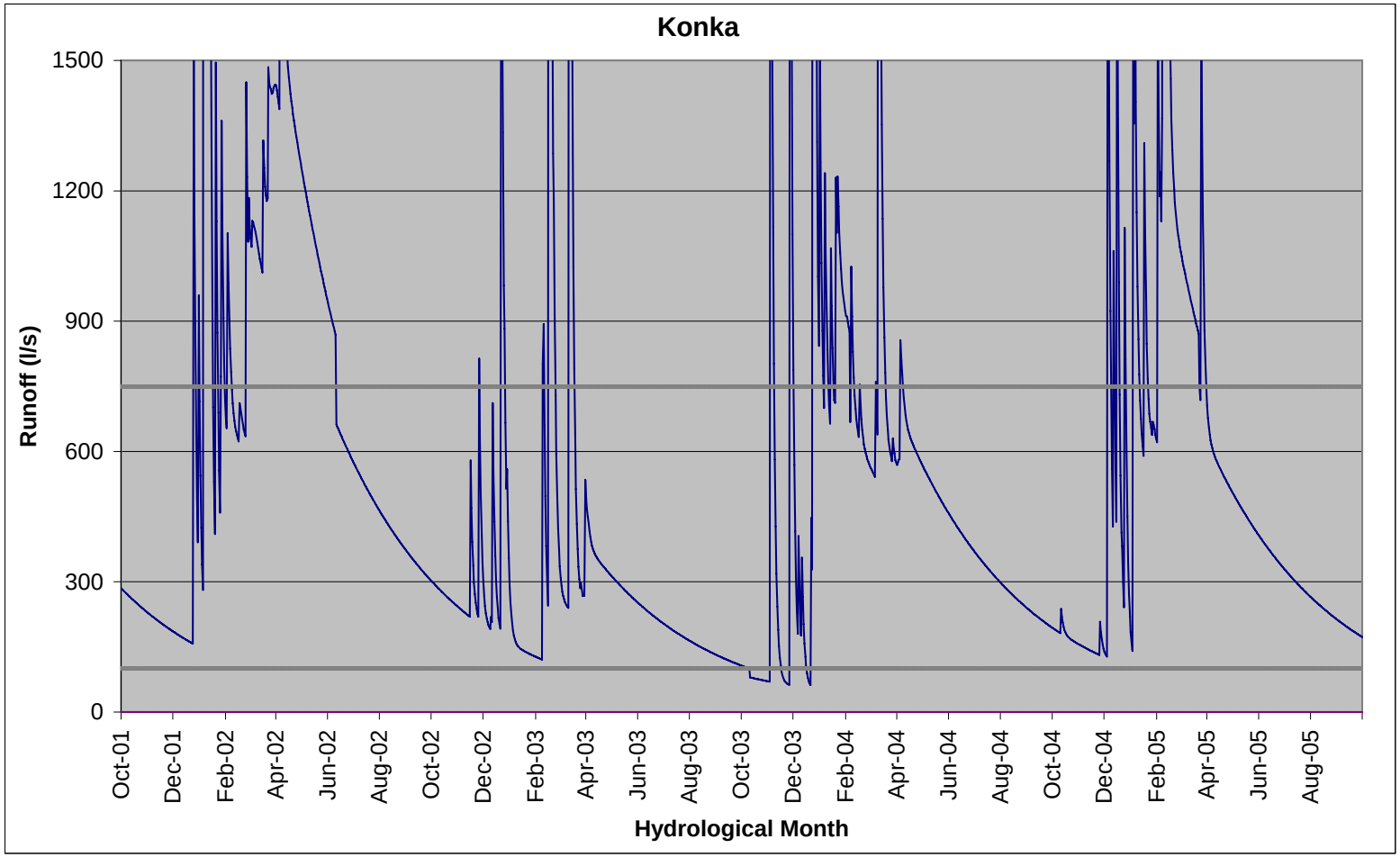


Figure 6 Lower Dipeta

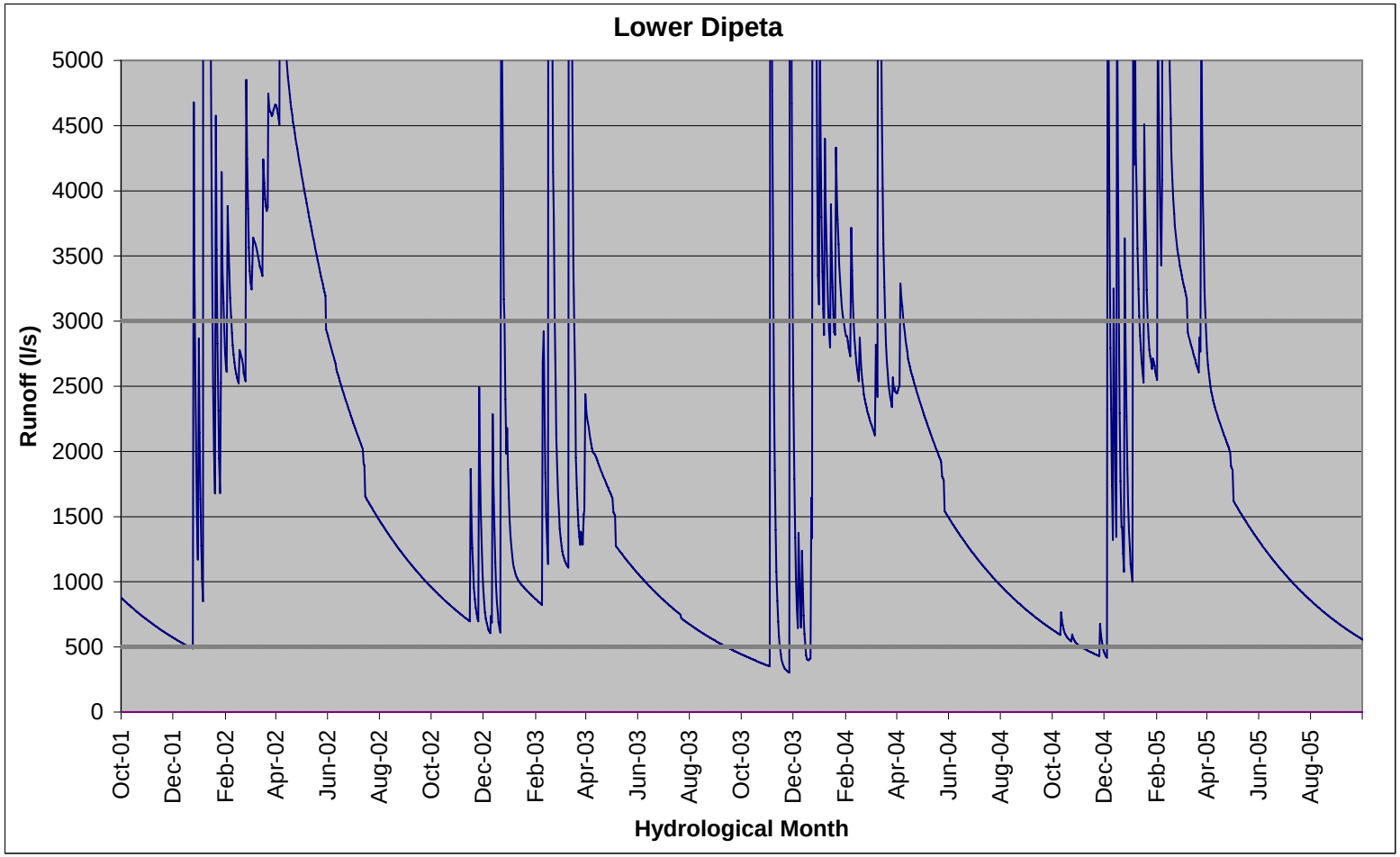


Figure 7 Upper Mofia

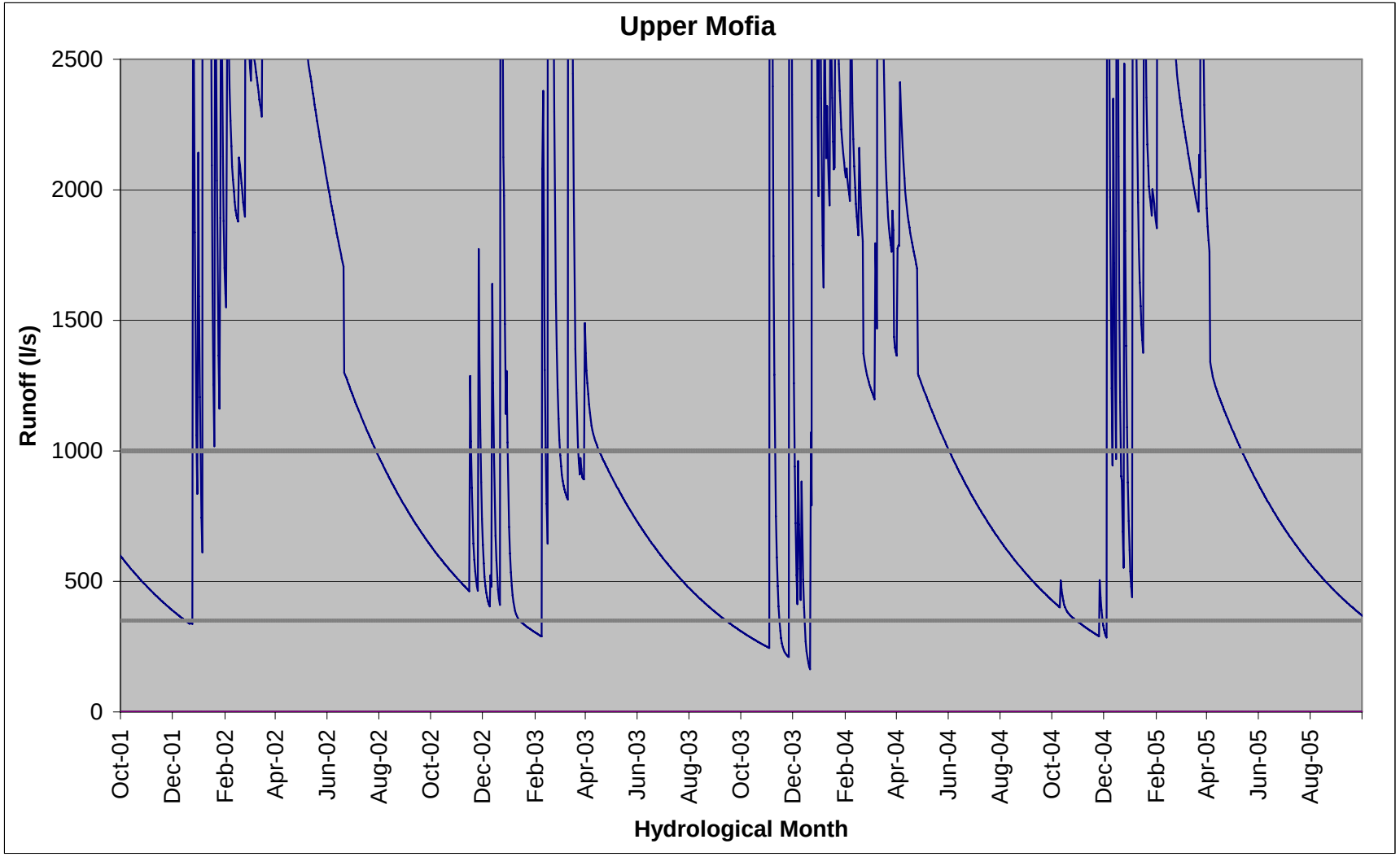


Figure 8 Kasana

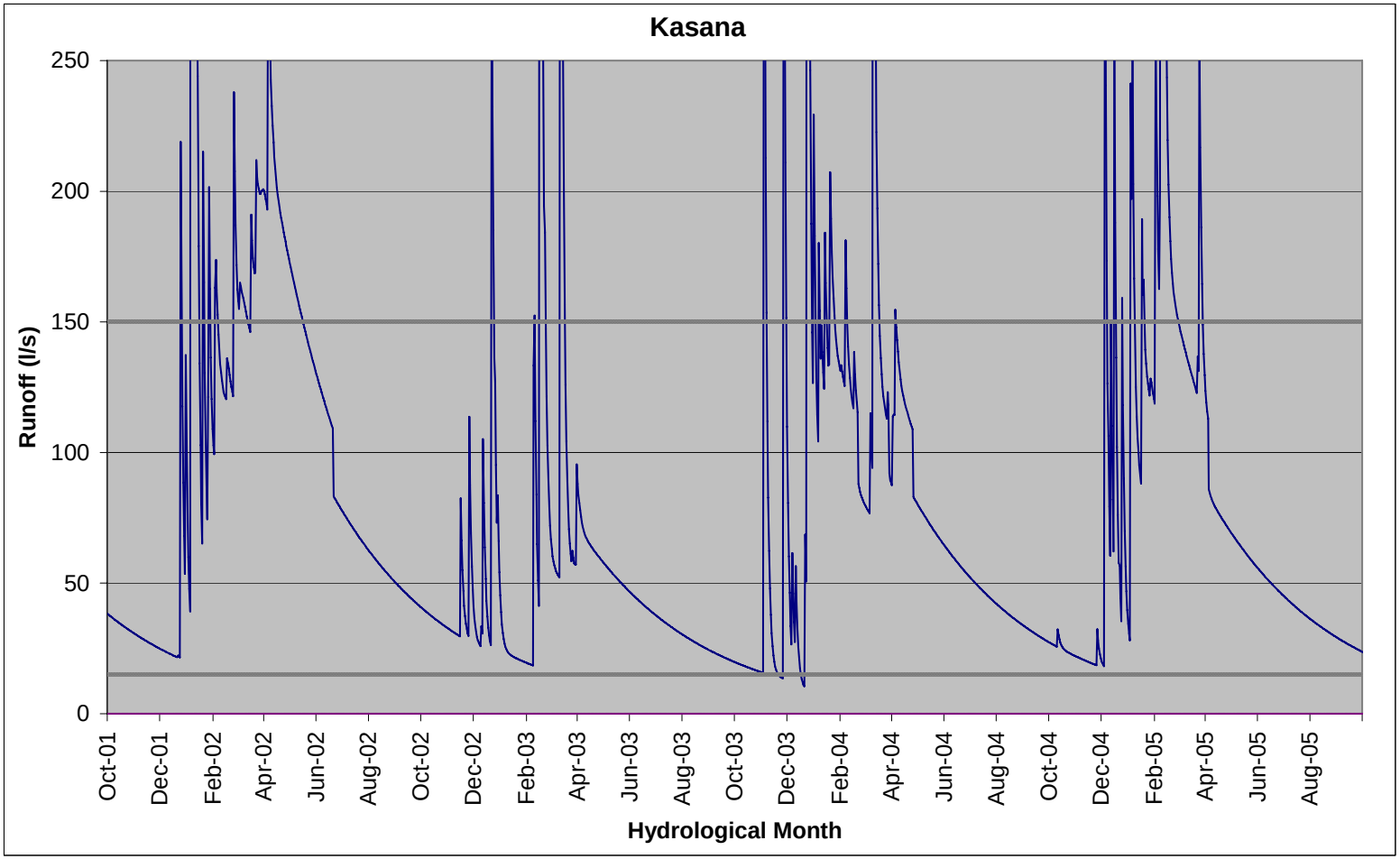


Figure 9 Mid Mofia

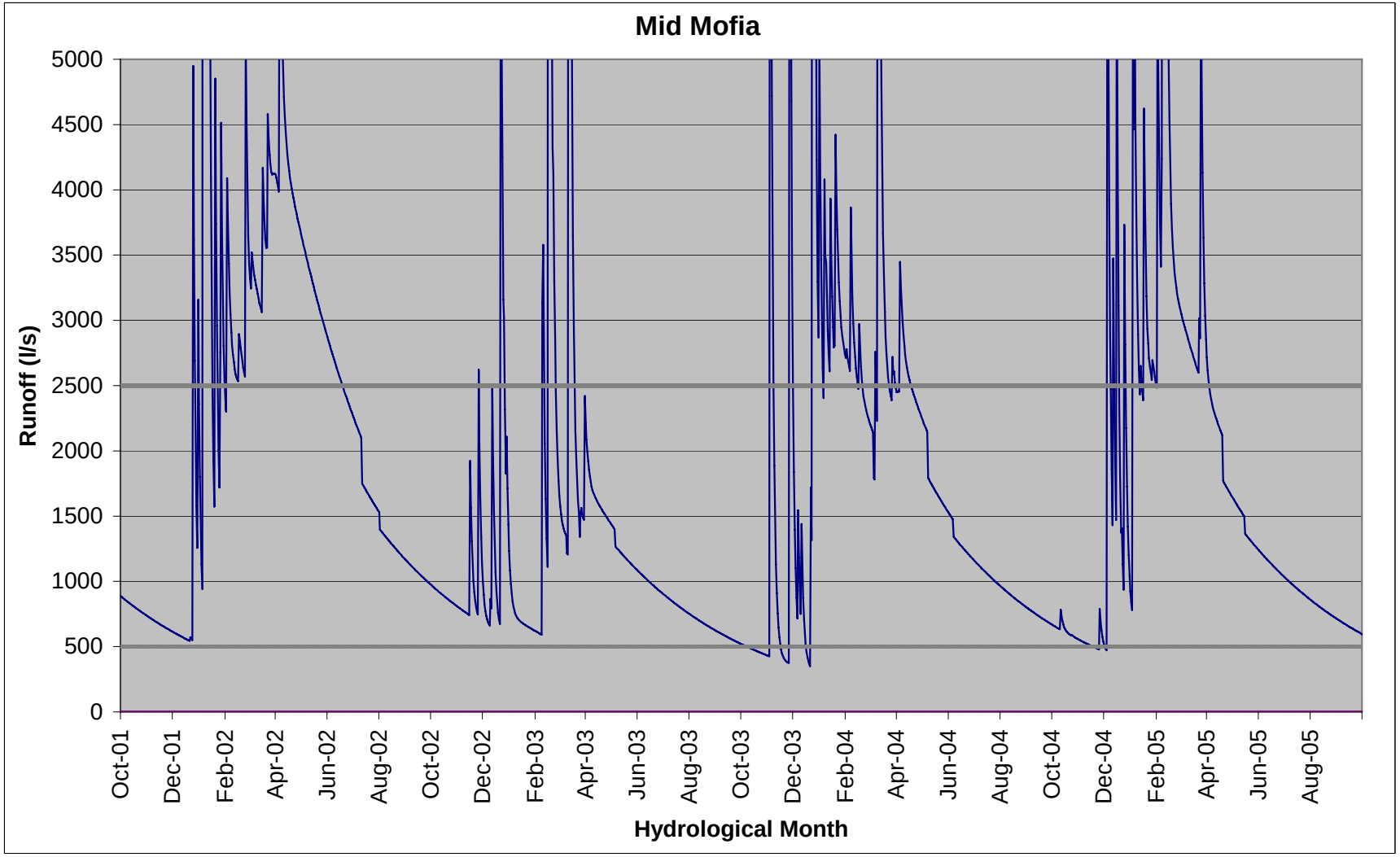
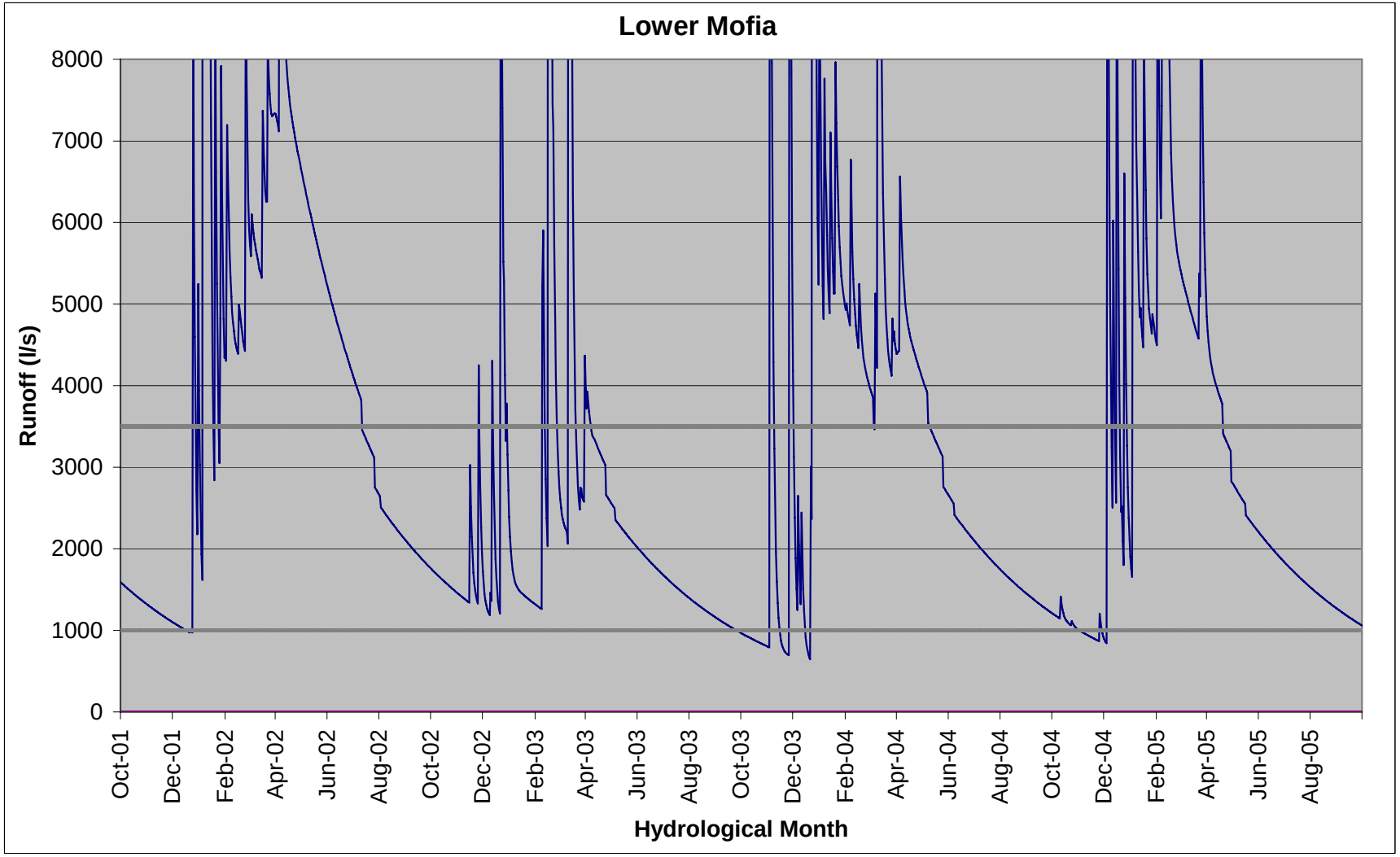


Figure 10 Lower Mofia



ATTACHMENT 5

AGRICULTURAL CATCHMENTS RESEARCH UNIT (ACRU) MENU– FILE INPUT DATA FOR THE VARIOUS SUBCATCHMENTS

Upper Dipeta

Menu	Variable	Description	Option / Value
Rainfall file organisation and information	IRAINF	File name assigned to daily rainfall/climate data	Lukatola.dat
	PPTCOR	Precipitation adjustment option	0: No adjustment to be made
	FORMAT	Format of daily climate data	Single
	MAP	Mean annual precipitation (mm)	1100
Streamflow file organisation	IOBSTQ	Availability of observed daily streamflow data	No
	IOBSPK	Availability of observed daily peak discharge data	No
	IOBOVR	Option to use observed streanflow data as streamflow input to downstream subcatchments	No
Dynamic file organisation	DYNAMIC	Option to invoke a dynamic input file	No: No dynamic input file to be used
Locality and catchment information	HEAD	General heading of this subcatchment	Upper Dipeta
	CLAREA	Area of subcatchment in km^2	8.82
	ELEV	Altitude in metres above mean sea level	1448
	IHEM	Hemisphere indicator	South
	IQUAD	Quadrant indicator	East
	ALAT	Latitude of the centre of subcatchment in degrees and minutes	10 38
	ALONG	Longitude of the centre of subcatchment in degrees and minutes	26 14
Length of record for simulation	IYSTRT	Start year of simulation	01/01/2001
	IYREND	End year of simulation	31/12/2006
Reference potential evaporation control variables	EQPET	Option to specify by which method the daily reference potential evaporation is to be derived	100: Expert system option
	IEIF	Availability of monthly means of evaporation pan equivalent values	Yes
	ILRF	Altitude correction for temperature values	No
	IWDF	Availability of monthly means of daily windrun values	No
	IRHF	Availability of monthly means of daily average relative humidity values	Yes
	ISNF	Availability of monthly means of daily sunshine duration values	No
	IRDF	Availability of mean monthly radiation flux densities	Yes
	IRDF	Availability of daily or monthly values of temperature, and windrun, and relative humidity, and sunshine duration, or incoming solar radiation	No
Reference potential evaporation input information	TMAX	Monthly means of daily maximum temperatures	See Table 2 of Report
	TMIN	Monthly means of daily minimum temperatures	See Table 2 of Report
	E	Monthly totals of A-Pan equivalent evaporation	See Table 2 of Report
	RH	Monthly means of daily average relative humidity	See Table 2 of Report
	PANCOR	Option to request monthly pan evaporation adjusment	1: Adjustment factor to be applied to all evapration values
	CORPAN	Monthly adjustment factor to be applied to evaporation pan data set	1.12
Catchment soils information	PEDINF	Adequacy of soils information	Yes
	ITEXT	Soil texture class	See Appendix B
	PEDDEP	Soil thickness information	See Appendix B
	DEPAHO	Thickness (m) of topsoil	0.35
	DEPBHO	Thickness (m) of subsoil	1.45
	WP1	Soil water content (m/m) at permanent wilting point for the topsoil	0.188
	WP2	Soil water content (m/m) at permanent wilting point for the subsoil	0.188
	FC1	Soil water content (m/m) at drained upper limit for the topsoil	0.307
	FC2	Soil water content (m/m) at drained upper limit for the subsoil	0.307
	PO1	Soil water content (m/m) at saturation for the topsoil	0.468
	PO2	Soil water content (m/m) at saturation for the subsoil	0.468
	ABRESP	Fraction of "saturated" soil water to be redistributed daily from topsoil into subsoil when topsoil is above drained upper limit	0.41
	BFRESP	Fraction of "saturated" soil water to be redistributed daily from subsoil into groundwater store when subsoil is above drained upper limit	0.41
	ICRACK	Option to account for cracking soils	0: No cracking soils
	SMAINI	Initial soil water content for the A horison expressed as a % of PAWC	0
	SMBINI	Initial soil water content for the B horison expressed as a % of PAWC	0
	SWLOPT	Is a statistical analysis of the soil water regime required	No
Catchment land cover information	LCOVER	Option to specify whether manually input or defualt values are to be used	No: Monthly default values to be used
		CROPNO	See Appendix C
	EFRDEP	Effective total rooting depth	1.8
Total evaporation control variables	EVTR	Option to determine how evaporation from the soil surface and from plant tissue are estimated	1: Es and Et are to be estimated as an entity
	FPAW	Do you want to use critical leaf water potential to establish plant water stress	Yes
	CONST	Fraction of plant available water at which plant stress sets in	-1200
	FOREST	Option for enhanced wet canopy evaporation	0: No forest vegetation
	CO2TRA	Option for simulating under enhanced atmospheric CO2 levels	0: No elevated CO2 concentrations
	TMPCUT	Mean temperature threshold for acive plant growth to take place	1
	IUNSAT	Is the unsaturated soil water redistribution to be included in the soil water budgeting	No
Streamflow simulation control varaibles	QFRESP	Stormflow response fraction of the catchment	0.3
	COFRU	Coefficient of the baseflow response	0.012
	SMDDEP	Effective depth of soil to be considered for the calculation of quickflow response	0.5
	IRUN	Should baseflow be included in the simualted runoff statistics	Yes
	ADJIMP	Fraction of catchment occupied by adjunct impervious areas	0
	DISIMP	Fraction of catchment occupied by disjunct impervious areas	0
	STOIMP	Impervoius area's initial abstraction	1
	COIAM	Monthly coefficient of initial abstraction	
	LYSIM	Is generated stromflow to be reinfiltrated	No
Peak discharge control variables	PEAK	Peak discharge option	No
Wetland simulation variables	IVLEI	Option to simulate wetland	No
Shallow groundwater analysis options	IGWATR		No
Irrigation option	IRRIGN		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No

Sokalwela

Menu	Variable	Description	Option / Value
Rainfall file organisation and information	IRAINF	File name assigned to daily rainfall/climate data	Lukatola.dat
	PPTCOR	Precipitation adjustment option	0: No adjustment to be made
	FORMAT	Format of daily climate data	Single
	MAP	Mean annual precipitation (mm)	1100
Streamflow file organisation	IOBSTQ	Availability of observed daily streamflow data	No
	IOBSPK	Availability of observed daily peak discharge data	No
	IOBOVR	Option to use observed streanflow data as streamflow input to downstream subcatchments	No
Dynamic file organisation	DYNAMIC	Option to invoke a dynamic input file	No: No dynamic input file to be used
Locality and catchment information	HEAD	General heading of this subcatchment	Sokalwela
	CLAREA	Area of subcatchment in km^2	7.72
	ELEV	Altitude in metres above mean sea level	1323
	IHEM	Hemisphere indicator	South
	IQUAD	Quadrant indicator	East
	ALAT	Latitude of the centre of subcatchment in degrees and minutes	10 35
	ALONG	Longitude of the centre of subcatchment in degrees and minutes	26 10
Length of record for simulation	IYSTRT	Start year of simulation	01/01/2001
	IYREND	End year of simulation	31/12/2006
Reference potential evaporation control variables	EQPET	Option to specify by which method the daily reference potential evaporation is to be derived	100: Expert system option
	IEIF	Availability of monthly means of evaporation pan equivalent values	Yes
	ILRF	Altitude correction for temperature values	No
	IWDF	Availability of monthly means of daily windrun values	No
	IRHF	Availability of monthly means of daily average relative humidity values	Yes
	ISNF	Availability of monthly means of daily sunshine duration values	No
	IRDF	Availability of mean monthly radiation flux densities	Yes
	IRDF	Availability of daily or monthly values of temperature, and windrun, and relative humidity, and sunshine duration, or incoming solar radiation	No
Reference potential evaporation input information	TMAX	Monthly means of daily maximum temperatures	See Table 2 of Report
	TMIN	Monthly means of daily minimum temperatures	See Table 2 of Report
	E	Monthly totals of A-Pan equivalent evaporation	See Table 2 of Report
	RH	Monthly means of daily average relative humidity	See Table 2 of Report
	PANCOR	Option to request monthly pan evaporation adjusment	1: Adjustment factor to be applied to all evapration values
	CORPAN	Monthly adjustment factor to be applied to evaporation pan data set	1.12
Catchment soils information	PEDINF	Adequacy of soils information	Yes
	ITEXT	Soil texture class	See Appendix B
	PEDDEP	Soil thickness information	See Appendix B
	DEPAHO	Thickness (m) of topsoil	0.35
	DEPBHO	Thickness (m) of subsoil	1.55
	WP1	Soil water content (m/m) at permanent wilting point for the topsoil	0.194
	WP2	Soil water content (m/m) at permanent wilting point for the subsoil	0.194
	FC1	Soil water content (m/m) at drained upper limit for the topsoil	0.314
	FC2	Soil water content (m/m) at drained upper limit for the subsoil	0.314
	PO1	Soil water content (m/m) at saturation for the topsoil	0.468
	PO2	Soil water content (m/m) at saturation for the subsoil	0.468
	ABRESP	Fraction of "saturated" soil water to be redistributed daily from topsoil into subsoil when topsoil is above drained upper limit	0.40
	BFRESP	Fraction of "saturated" soil water to be redistributed daily from subsoil into groundwater store when subsoil is above drained upper limit	0.40
	ICRACK	Option to account for cracking soils	0: No cracking soils
	SMAINI	Initial soil water content for the A horison expressed as a % of PAWC	0
	SMBINI	Initial soil water content for the B horison expressed as a % of PAWC	0
	SWLOPT	Is a statistical analysis of the soil water regime required	No
Catchment land cover information	LCOVER	Option to specify whether manually input or defualt values are to be used	No: Monthly default values to be used
		CROPNO	See Appendix C
	EFRDEP	Effective total rooting depth	1.9
Total evaporation control variables	EVTR	Option to determine how evaporation from the soil surface and from plant tissue are estimated	1: Es and Et are to be estimated as an entity
	FPAW	Do you want to use critical leaf water potential to establish plant water stress	Yes
	CONST	Fraction of plant available water at which plant stress sets in	-1200
	FOREST	Option for enhanced wet canopy evaporation	0: No forest vegetation
	CO2TRA	Option for simulating under enhanced atmospheric CO2 levels	0: No elevated CO2 concentrations
	TMPCUT	Mean temperature threshold for acive plant growth to take place	1
	IUNSAT	Is the unsaturated soil water redistribution to be included in the soil water budgeting	No
Streamflow simulation control varaibles	QFRESP	Stormflow response fraction of the catchment	0.3
	COFRU	Coefficient of the baseflow response	0.008
	SMDDEP	Effective depth of soil to be considered for the calculation of quickflow response	0.5
	IRUN	Should baseflow be included in the simualted runoff statistics	Yes
	ADJIMP	Fraction of catchment occupied by adjunct impervious areas	0
	DISIMP	Fraction of catchment occupied by disjunct impervious areas	0
	STOIMP	Impervoius area's initial abstraction	1
	COIAM	Monthly coefficient of initial abstraction	
	LYSIM	Is generated stromflow to be reinfiltrated	No
Peak discharge control variables	PEAK	Peak discharge option	No
Wetland simulation variables	IVLEI	Option to simulate wetland	No
Shallow groundwater analysis options	IGWATR		No
Irrigation option	IRRIGN		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No

Shimpidi

Menu	Variable	Description	Option / Value
Rainfall file organisation and information	IRAINF	File name assigned to daily rainfall/climate data	Lukatola.dat
	PPTCOR	Precipitation adjustment option	0: No adjustment to be made
	FORMAT	Format of daily climate data	Single
	MAP	Mean annual precipitation (mm)	1100
Streamflow file organisation	IOBSTQ	Availability of observed daily streamflow data	No
	IOBSPK	Availability of observed daily peak discharge data	No
	IOBOVR	Option to use observed streanflow data as streamflow input to downstream subcatchments	No
Dynamic file organisation	DYNAMIC	Option to invoke a dynamic input file	No: No dynamic input file to be used
Locality and catchment information	HEAD	General heading of this subcatchment	Shimpidi
	CLAREA	Area of subcatchment in km^2	12.01
	ELEV	Altitude in metres above mean sea level	1388
	IHEM	Hemisphere indicator	South
	IQUAD	Quadrant indicator	East
	ALAT	Latitude of the centre of subcatchment in degrees and minutes	10 35
	ALONG	Longitude of the centre of subcatchment in degrees and minutes	26 12
Length of record for simulation	IYSTRT	Start year of simulation	01/01/2001
	IYREND	End year of simulation	31/12/2006
Reference potential evaporation control variables	EQPET	Option to specify by which method the daily reference potential evaporation is to be derived	100: Expert system option
	IEIF	Availability of monthly means of evaporation pan equivalent values	Yes
	ILRF	Altitude correction for temperature values	No
	IWDF	Availability of monthly means of daily windrun values	No
	IRHF	Availability of monthly means of daily average relative humidity values	Yes
	ISNF	Availability of monthly means of daily sunshine duration values	No
	IRDF	Availability of mean monthly radiation flux densities	Yes
	IRDF	Availability of daily or monthly values of temperature, and windrun, and relative humidity, and sunshine duration, or incoming solar radiation	No
Reference potential evaporation input information	TMAX	Monthly means of daily maximum temperatures	See Table 2 of Report
	TMIN	Monthly means of daily minimum temperatures	See Table 2 of Report
	E	Monthly totals of A-Pan equivalent evaporation	See Table 2 of Report
	RH	Monthly means of daily average relative humidity	See Table 2 of Report
	PANCOR	Option to request monthly pan evaporation adjusment	1: Adjustment factor to be applied to all evapration values
	CORPAN	Monthly adjustment factor to be applied to evaporation pan data set	1.12
Catchment soils information	PEDINF	Adequacy of soils information	Yes
	ITEXT	Soil texture class	See Appendix B
	PEDDEP	Soil thickness information	See Appendix B
	DEPAHO	Thickness (m) of topsoil	0.35
	DEPBHO	Thickness (m) of subsoil	1.4
	WP1	Soil water content (m/m) at permanent wilting point for the topsoil	0.191
	WP2	Soil water content (m/m) at permanent wilting point for the subsoil	0.191
	FC1	Soil water content (m/m) at drained upper limit for the topsoil	0.31
	FC2	Soil water content (m/m) at drained upper limit for the subsoil	0.31
	PO1	Soil water content (m/m) at saturation for the topsoil	0.468
	PO2	Soil water content (m/m) at saturation for the subsoil	0.468
	ABRESP	Fraction of "saturated" soil water to be redistributed daily from topsoil into subsoil when topsoil is above drained upper limit	0.40
	BFRESP	Fraction of "saturated" soil water to be redistributed daily from subsoil into groundwater store when subsoil is above drained upper limit	0.40
	ICRACK	Option to account for cracking soils	0: No cracking soils
	SMAINI	Initial soil water content for the A horison expressed as a % of PAWC	0
	SMBINI	Initial soil water content for the B horison expressed as a % of PAWC	0
	SWLOPT	Is a statistical analysis of the soil water regime required	No
Catchment land cover information	LCOVER	Option to specify whether manually input or defualt values are to be used	No: Monthly default values to be used
		CROPNO	See Appendix C
	EFRDEP	Effective total rooting depth	1.75
Total evaporation control variables	EVTR	Option to determine how evaporation from the soil surface and from plant tissue are estimated	1: Es and Et are to be estimated as an entity
	FPAW	Do you want to use critical leaf water potential to establish plant water stress	Yes
	CONST	Fraction of plant available water at which plant stress sets in	-1200
	FOREST	Option for enhanced wet canopy evaporation	0: No forest vegetation
	CO2TRA	Option for simulating under enhanced atmospheric CO2 levels	0: No elevated CO2 concentrations
	TMPCUT	Mean temperature threshold for acive plant growth to take place	1
	IUNSAT	Is the unsaturated soil water redistribution to be included in the soil water budgeting	No
Streamflow simulation control varaibles	QFRESP	Stormflow response fraction of the catchment	0.3
	COFRU	Coefficient of the baseflow response	0.008
	SMDDEP	Effective depth of soil to be considered for the calculation of quickflow response	0.5
	IRUN	Should baseflow be included in the simualted runoff statistics	Yes
	ADJIMP	Fraction of catchment occupied by adjunct impervious areas	0
	DISIMP	Fraction of catchment occupied by disjunct impervious areas	0
	STOIMP	Impervoius area's initial abstraction	1
	COIAM	Monthly coefficient of initial abstraction	
	LYSIM	Is generated stromflow to be reinfiltrated	No
Peak discharge control variables	PEAK	Peak discharge option	No
Wetland simulation variables	IVLEI	Option to simulate wetland	No
Shallow groundwater analysis options	IGWATR		No
Irrigation option	IRRIGN		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No

Mid Dipeta

Menu	Variable	Description	Option / Value
Rainfall file organisation and information	IRAINF	File name assigned to daily rainfall/climate data	Lukatola.dat
	PPTCOR	Precipitation adjustment option	0: No adjustment to be made
	FORMAT	Format of daily climate data	Single
	MAP	Mean annual precipitation (mm)	1100
Streamflow file organisation	IOBSTQ	Availability of observed daily streamflow data	No
	IOBSPK	Availability of observed daily peak discharge data	No
	IOBOVR	Option to use observed streanflow data as streamflow input to downstream subcatchments	No
Dynamic file organisation	DYNAMIC	Option to invoke a dynamic input file	No: No dynamic input file to be used
Locality and catchment information	HEAD	General heading of this subcatchment	Mid Dipeta
	CLAREA	Area of subcatchment in km^2	97.51
	ELEV	Altitude in metres above mean sea level	1370
	IHEM	Hemisphere indicator	South
	IQUAD	Quadrant indicator	East
	ALAT	Latitude of the centre of subcatchment in degrees and minutes	10 38
	ALONG	Longitude of the centre of subcatchment in degrees and minutes	26 14
Length of record for simulation	IYSTRT	Start year of simulation	01/01/2001
	IYREND	End year of simulation	31/12/2006
Reference potential evaporation control variables	EQPET	Option to specify by which method the daily reference potential evaporation is to be derived	100: Expert system option
	IEIF	Availability of monthly means of evaporation pan equivalent values	Yes
	ILRF	Altitude correction for temperature values	No
	IWDF	Availability of monthly means of daily windrun values	No
	IRHF	Availability of monthly means of daily average relative humidity values	Yes
	ISNF	Availability of monthly means of daily sunshine duration values	No
	IRDF	Availability of mean monthly radiation flux densities	Yes
	IRDF	Availability of daily or monthly values of temperature, and windrun, and relative humidity, and sunshine duration, or incoming solar radiation	No
Reference potential evaporation input information	TMAX	Monthly means of daily maximum temperatures	See Table 2 of Report
	TMIN	Monthly means of daily minimum temperatures	See Table 2 of Report
	E	Monthly totals of A-Pan equivalent evaporation	See Table 2 of Report
	RH	Monthly means of daily average relative humidity	See Table 2 of Report
	PANCOR	Option to request monthly pan evaporation adjusment	1: Adjustment factor to be applied to all evapration values
	CORPAN	Monthly adjustment factor to be applied to evaporation pan data set	1.12
Catchment soils information	PEDINF	Adequacy of soils information	Yes
	ITEXT	Soil texture class	See Appendix B
	PEDDEP	Soil thickness information	See Appendix B
	DEPAHO	Thickness (m) of topsoil	0.35
	DEPBHO	Thickness (m) of subsoil	1.5
	WP1	Soil water content (m/m) at permanent wilting point for the topsoil	0.192
	WP2	Soil water content (m/m) at permanent wilting point for the subsoil	0.192
	FC1	Soil water content (m/m) at drained upper limit for the topsoil	0.311
	FC2	Soil water content (m/m) at drained upper limit for the subsoil	0.311
	PO1	Soil water content (m/m) at saturation for the topsoil	0.468
	PO2	Soil water content (m/m) at saturation for the subsoil	0.468
	ABRESP	Fraction of "saturated" soil water to be redistributed daily from topsoil into subsoil when topsoil is above drained upper limit	0.40
	BFRESP	Fraction of "saturated" soil water to be redistributed daily from subsoil into groundwater store when subsoil is above drained upper limit	0.40
	ICRACK	Option to account for cracking soils	0: No cracking soils
	SMAINI	Initial soil water content for the A horison expressed as a % of PAWC	0
	SMBINI	Initial soil water content for the B horison expressed as a % of PAWC	0
	SWLOPT	Is a statistical analysis of the soil water regime required	No
Catchment land cover information	LCOVER	Option to specify whether manually input or defualt values are to be used	No: Monthly default values to be used
		CROPNO	See Appendix C
	EFRDEP	Effective total rooting depth	1.85
Total evaporation control variables	EVTR	Option to determine how evaporation from the soil surface and from plant tissue are estimated	1: Es and Et are to be estimated as an entity
	FPAW	Do you want to use critical leaf water potential to establish plant water stress	Yes
	CONST	Fraction of plant available water at which plant stress sets in	-1200
	FOREST	Option for enhanced wet canopy evaporation	0: No forest vegetation
	CO2TRA	Option for simulating under enhanced atmospheric CO2 levels	0: No elevated CO2 concentrations
	TMPCUT	Mean temperature threshold for acive plant growth to take place	1
	IUNSAT	Is the unsaturated soil water redistribution to be included in the soil water budgeting	No
Streamflow simulation control varaibles	QFRESP	Stormflow response fraction of the catchment	0.3
	COFRU	Coefficient of the baseflow response	0.009
	SMDDEP	Effective depth of soil to be considered for the calculation of quickflow response	0.5
	IRUN	Should baseflow be included in the simualted runoff statistics	Yes
	ADJIMP	Fraction of catchment occupied by adjunct impervious areas	0
	DISIMP	Fraction of catchment occupied by disjunct impervious areas	0
	STOIMP	Impervoius area's initial abstraction	1
	COIAM	Monthly coefficient of initial abstraction	
	LYSIM	Is generated stromflow to be reinfiltrated	No
Peak discharge control variables	PEAK	Peak discharge option	No
Wetland simulation variables	IVLEI	Option to simulate wetland	No
Shallow groundwater analysis options	IGWATR		No
Irrigation option	IRRIGN		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No

Konka

Menu	Variable	Description	Option / Value
Rainfall file organisation and information	IRAINF	File name assigned to daily rainfall/climate data	Lukatola.dat
	PPTCOR	Precipitation adjustment option	0: No adjustment to be made
	FORMAT	Format of daily climate data	Single
	MAP	Mean annual precipitation (mm)	1100
Streamflow file organisation	IOBSTQ	Availability of observed daily streamflow data	No
	IOBSPK	Availability of observed daily peak discharge data	No
	IOBOVR	Option to use observed streanflow data as streamflow input to downstream subcatchments	No
Dynamic file organisation	DYNAMIC	Option to invoke a dynamic input file	No: No dynamic input file to be used
Locality and catchment information	HEAD	General heading of this subcatchment	Konka
	CLAREA	Area of subcatchment in km^2	13.99
	ELEV	Altitude in metres above mean sea level	1238
	IHEM	Hemisphere indicator	South
	IQUAD	Quadrant indicator	East
	ALAT	Latitude of the centre of subcatchment in degrees and minutes	10 38
	ALONG	Longitude of the centre of subcatchment in degrees and minutes	26 14
Length of record for simulation	IYSTRT	Start year of simulation	01/01/2001
	IYREND	End year of simulation	31/12/2006
Reference potential evaporation control variables	EQPET	Option to specify by which method the daily reference potential evaporation is to be derived	100: Expert system option
	IEIF	Availability of monthly means of evaporation pan equivalent values	Yes
	ILRF	Altitude correction for temperature values	No
	IWDF	Availability of monthly means of daily windrun values	No
	IRHF	Availability of monthly means of daily average relative humidity values	Yes
	ISNF	Availability of monthly means of daily sunshine duration values	No
	IRDF	Availability of mean monthly radiation flux densities	Yes
	IRDF	Availability of daily or monthly values of temperature, and windrun, and relative humidity, and sunshine duration, or incoming solar radiation	No
Reference potential evaporation input information	TMAX	Monthly means of daily maximum temperatures	See Table 2 of Report
	TMIN	Monthly means of daily minimum temperatures	See Table 2 of Report
	E	Monthly totals of A-Pan equivalent evaporation	See Table 2 of Report
	RH	Monthly means of daily average relative humidity	See Table 2 of Report
	PANCOR	Option to request monthly pan evaporation adjusment	1: Adjustment factor to be applied to all evapration values
	CORPAN	Monthly adjustment factor to be applied to evaporation pan data set	1.12
Catchment soils information	PEDINF	Adequacy of soils information	Yes
	ITEXT	Soil texture class	See Appendix B
	PEDDEP	Soil thickness information	See Appendix B
	DEPAHO	Thickness (m) of topsoil	0.35
	DEPBHO	Thickness (m) of subsoil	1.3
	WP1	Soil water content (m/m) at permanent wilting point for the topsoil	0.189
	WP2	Soil water content (m/m) at permanent wilting point for the subsoil	0.189
	FC1	Soil water content (m/m) at drained upper limit for the topsoil	0.308
	FC2	Soil water content (m/m) at drained upper limit for the subsoil	0.308
	PO1	Soil water content (m/m) at saturation for the topsoil	0.468
	PO2	Soil water content (m/m) at saturation for the subsoil	0.468
	ABRESP	Fraction of "saturated" soil water to be redistributed daily from topsoil into subsoil when topsoil is above drained upper limit	0.41
	BFRESP	Fraction of "saturated" soil water to be redistributed daily from subsoil into groundwater store when subsoil is above drained upper limit	0.41
	ICRACK	Option to account for cracking soils	0: No cracking soils
	SMAINI	Initial soil water content for the A horison expressed as a % of PAWC	0
	SMBINI	Initial soil water content for the B horison expressed as a % of PAWC	0
	SWLOPT	Is a statistical analysis of the soil water regime required	No
Catchment land cover information	LCOVER	Option to specify whether manually input or defualt values are to be used	No: Monthly default values to be used
		CROPNO	See Appendix C
	EFRDEP	Effective total rooting depth	1.65
Total evaporation control variables	EVTR	Option to determine how evaporation from the soil surface and from plant tissue are estimated	1: Es and Et are to be estimated as an entity
	FPAW	Do you want to use critical leaf water potential to establish plant water stress	Yes
	CONST	Fraction of plant available water at which plant stress sets in	-1200
	FOREST	Option for enhanced wet canopy evaporation	0: No forest vegetation
	CO2TRA	Option for simulating under enhanced atmospheric CO2 levels	0: No elevated CO2 concentrations
	TMPCUT	Mean temperature threshold for acive plant growth to take place	1
	IUNSAT	Is the unsaturated soil water redistribution to be included in the soil water budgeting	No
Streamflow simulation control varaibles	QFRESP	Stormflow response fraction of the catchment	0.3
	COFRU	Coefficient of the baseflow response	0.007
	SMDDEP	Effective depth of soil to be considered for the calculation of quickflow response	0.5
	IRUN	Should baseflow be included in the simualted runoff statistics	Yes
	ADJIMP	Fraction of catchment occupied by adjunct impervious areas	0
	DISIMP	Fraction of catchment occupied by disjunct impervious areas	0
	STOIMP	Impervoius area's initial abstraction	1
	COIAM	Monthly coefficient of initial abstraction	
	LYSIM	Is generated stromflow to be reinfiltrated	No
Peak discharge control variables	PEAK	Peak discharge option	No
Wetland simulation variables	IVLEI	Option to simulate wetland	No
Shallow groundwater analysis options	IGWATR		No
Irrigation option	IRRIGN		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No

Lower Dipeta

Menu	Variable	Description	Option / Value
Rainfall file organisation and information	IRAINF	File name assigned to daily rainfall/climate data	Lukatola.dat
	PPTCOR	Precipitation adjustment option	0: No adjustment to be made
	FORMAT	Format of daily climate data	Single
	MAP	Mean annual precipitation (mm)	1100
Streamflow file organisation	IOBSTQ	Availability of observed daily streamflow data	No
	IOBSPK	Availability of observed daily peak discharge data	No
	IOBOVR	Option to use observed streanflow data as streamflow input to downstream subcatchments	No
Dynamic file organisation	DYNAMIC	Option to invoke a dynamic input file	No: No dynamic input file to be used
Locality and catchment information	HEAD	General heading of this subcatchment	Lower Dipeta
	CLAREA	Area of subcatchment in km^2	54.79
	ELEV	Altitude in metres above mean sea level	1287
	IHEM	Hemisphere indicator	South
	IQUAD	Quadrant indicator	East
	ALAT	Latitude of the centre of subcatchment in degrees and minutes	10 38
	ALONG	Longitude of the centre of subcatchment in degrees and minutes	26 14
Length of record for simulation	IYSTRT	Start year of simulation	01/01/2001
	IYREND	End year of simulation	31/12/2006
Reference potential evaporation control variables	EQPET	Option to specify by which method the daily reference potential evaporation is to be derived	100: Expert system option
	IEIF	Availability of monthly means of evaporation pan equivalent values	Yes
	ILRF	Altitude correction for temperature values	No
	IWDF	Availability of monthly means of daily windrun values	No
	IRHF	Availability of monthly means of daily average relative humidity values	Yes
	ISNF	Availability of monthly means of daily sunshine duration values	No
	IRDF	Availability of mean monthly radiation flux densities	Yes
	IRDF	Availability of daily or monthly values of temperature, and windrun, and relative humidity, and sunshine duration, or incoming solar radiation	No
Reference potential evaporation input information	TMAX	Monthly means of daily maximum temperatures	See Table 2 of Report
	TMIN	Monthly means of daily minimum temperatures	See Table 2 of Report
	E	Monthly totals of A-Pan equivalent evaporation	See Table 2 of Report
	RH	Monthly means of daily average relative humidity	See Table 2 of Report
	PANCOR	Option to request monthly pan evaporation adjusment	1: Adjustment factor to be applied to all evapration values
	CORPAN	Monthly adjustment factor to be applied to evaporation pan data set	1.12
Catchment soils information	PEDINF	Adequacy of soils information	Yes
	ITEXT	Soil texture class	See Appendix B
	PEDDEP	Soil thickness information	See Appendix B
	DEPAHO	Thickness (m) of topsoil	0.35
	DEPBHO	Thickness (m) of subsoil	1.45
	WP1	Soil water content (m/m) at permanent wilting point for the topsoil	0.191
	WP2	Soil water content (m/m) at permanent wilting point for the subsoil	0.191
	FC1	Soil water content (m/m) at drained upper limit for the topsoil	0.309
	FC2	Soil water content (m/m) at drained upper limit for the subsoil	0.309
	PO1	Soil water content (m/m) at saturation for the topsoil	0.468
	PO2	Soil water content (m/m) at saturation for the subsoil	0.468
	ABRESP	Fraction of "saturated" soil water to be redistributed daily from topsoil into subsoil when topsoil is above drained upper limit	0.40
	BFRESP	Fraction of "saturated" soil water to be redistributed daily from subsoil into groundwater store when subsoil is above drained upper limit	0.40
	ICRACK	Option to account for cracking soils	0: No cracking soils
	SMAINI	Initial soil water content for the A horison expressed as a % of PAWC	0
	SMBINI	Initial soil water content for the B horison expressed as a % of PAWC	0
	SWLOPT	Is a statistical analysis of the soil water regime required	No
Catchment land cover information	LCOVER	Option to specify whether manually input or defualt values are to be used	No: Monthly default values to be used
		CROPNO	See Appendix C
	EFRDEP	Effective total rooting depth	1.8
Total evaporation control variables	EVTR	Option to determine how evaporation from the soil surface and from plant tissue are estimated	1: Es and Et are to be estimated as an entity
	FPAW	Do you want to use critical leaf water potential to establish plant water stress	Yes
	CONST	Fraction of plant available water at which plant stress sets in	-1200
	FOREST	Option for enhanced wet canopy evaporation	0: No forest vegetation
	CO2TRA	Option for simulating under enhanced atmospheric CO2 levels	0: No elevated CO2 concentrations
	TMPCUT	Mean temperature threshold for acive plant growth to take place	1
	IUNSAT	Is the unsaturated soil water redistribution to be included in the soil water budgeting	No
Streamflow simulation control varaibles	QFRESP	Stormflow response fraction of the catchment	0.3
	COFRU	Coefficient of the baseflow response	0.007
	SMDDEP	Effective depth of soil to be considered for the calculation of quickflow response	0.5
	IRUN	Should baseflow be included in the simualted runoff statistics	Yes
	ADJIMP	Fraction of catchment occupied by adjunct impervious areas	0
	DISIMP	Fraction of catchment occupied by disjunct impervious areas	0
	STOIMP	Impervoius area's initial abstraction	1
	COIAM	Monthly coefficient of initial abstraction	
	LYSIM	Is generated stromflow to be reinfiltrated	No
Peak discharge control variables	PEAK	Peak discharge option	No
Wetland simulation variables	IVLEI	Option to simulate wetland	No
Shallow groundwater analysis options	IGWATR		No
Irrigation option	IRRIGN		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No

Upper Mofia

Menu	Variable	Description	Option / Value
Rainfall file organisation and information	IRAINF	File name assigned to daily rainfall/climate data	Lukatola.dat
	PPTCOR	Precipitation adjustment option	0: No adjustment to be made
	FORMAT	Format of daily climate data	Single
	MAP	Mean annual precipitation (mm)	1100
Streamflow file organisation	IOBSTQ	Availability of observed daily streamflow data	No
	IOBSPK	Availability of observed daily peak discharge data	No
	IOBOVR	Option to use observed streanflow data as streamflow input to downstream subcatchments	No
Dynamic file organisation	DYNAMIC	Option to invoke a dynamic input file	No: No dynamic input file to be used
Locality and catchment information	HEAD	General heading of this subcatchment	Upper Mofya
	CLAREA	Area of subcatchment in km^2	161.2
	ELEV	Altitude in metres above mean sea level	1468
	IHEM	Hemisphere indicator	South
	IQUAD	Quadrant indicator	East
	ALAT	Latitude of the centre of subcatchment in degrees and minutes	10 31
	ALONG	Longitude of the centre of subcatchment in degrees and minutes	26 06
Length of record for simulation	IYSTRT	Start year of simulation	01/01/2001
	IYREND	End year of simulation	31/12/2006
Reference potential evaporation control variables	EQPET	Option to specify by which method the daily reference potential evaporation is to be derived	100: Expert system option
	IEIF	Availability of monthly means of evaporation pan equivalent values	Yes
	ILRF	Altitude correction for temperature values	No
	IWDF	Availability of monthly means of daily windrun values	No
	IRHF	Availability of monthly means of daily average relative humidity values	Yes
	ISNF	Availability of monthly means of daily sunshine duration values	No
	IRDF	Availability of mean monthly radiation flux densities	Yes
	IRDF	Availability of daily or monthly values of temperature, and windrun, and relative humidity, and sunshine duration, or incoming solar radiation	No
Reference potential evaporation input information	TMAX	Monthly means of daily maximum temperatures	See Table 2 of Report
	TMIN	Monthly means of daily minimum temperatures	See Table 2 of Report
	E	Monthly totals of A-Pan equivalent evaporation	See Table 2 of Report
	RH	Monthly means of daily average relative humidity	See Table 2 of Report
	PANCOR	Option to request monthly pan evaporation adjusment	1: Adjustment factor to be applied to all evapration values
	CORPAN	Monthly adjustment factor to be applied to evaporation pan data set	1.12
Catchment soils information	PEDINF	Adequacy of soils information	Yes
	ITEXT	Soil texture class	See Appendix B
	PEDDEP	Soil thickness information	See Appendix B
	DEPAHO	Thickness (m) of topsoil	0.35
	DEPBHO	Thickness (m) of subsoil	1.25
	WP1	Soil water content (m/m) at permanent wilting point for the topsoil	0.195
	WP2	Soil water content (m/m) at permanent wilting point for the subsoil	0.195
	FC1	Soil water content (m/m) at drained upper limit for the topsoil	0.312
	FC2	Soil water content (m/m) at drained upper limit for the subsoil	0.312
	PO1	Soil water content (m/m) at saturation for the topsoil	0.468
	PO2	Soil water content (m/m) at saturation for the subsoil	0.468
	ABRESP	Fraction of "saturated" soil water to be redistributed daily from topsoil into subsoil when topsoil is above drained upper limit	0.40
	BFRESP	Fraction of "saturated" soil water to be redistributed daily from subsoil into groundwater store when subsoil is above drained upper limit	0.40
	ICRACK	Option to account for cracking soils	0: No cracking soils
	SMAINI	Initial soil water content for the A horison expressed as a % of PAWC	0
	SMBINI	Initial soil water content for the B horison expressed as a % of PAWC	0
	SWLOPT	Is a statistical analysis of the soil water regime required	No
Catchment land cover information	LCOVER	Option to specify whether manually input or defualt values are to be used	No: Monthly default values to be used
	CROPNO		See Appendix C
	EFRDEP	Effective total rooting depth	1.8
Total evaporation control variables	EVTR	Option to determine how evaporation from the soil surface and from plant tissue are estimated	1: Es and Et are to be estimated as an entity
	FPAW	Do you want to use critical leaf water potential to establish plant water stress	Yes
	CONST	Fraction of plant available water at which plant stress sets in	-1200
	FOREST	Option for enhanced wet canopy evaporation	0: No forest vegetation
	CO2TRA	Option for simulating under enhanced atmospheric CO2 levels	0: No elevated CO2 concentrations
	TMPCUT	Mean temperature threshold for acive plant growth to take place	1
	IUNSAT	Is the unsaturated soil water redistribution to be included in the soil water budgeting	No
Streamflow simulation control varaibles	QFRESP	Stormflow response fraction of the catchment	0.3
	COFRU	Coefficient of the baseflow response	0.007
	SMDDEP	Effective depth of soil to be considered for the calculation of quickflow response	0.5
	IRUN	Should baseflow be included in the simualted runoff statistics	Yes
	ADJIMP	Fraction of catchment occupied by adjunct impervious areas	0
	DISIMP	Fraction of catchment occupied by disjunct impervious areas	0
	STOIMP	Impervoius area's initial abstraction	1
	COIAM	Monthly coefficient of initial abstraction	
	LYSIM	Is generated stromflow to be reinfiltrated	No
Peak discharge control variables	PEAK	Peak discharge option	No
Wetland simulation variables	IVLEI	Option to simulate wetland	No
Shallow groundwater analysis options	IGWATR		No
Irrigation option	IRRIGN		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No

Kasana

Menu	Variable	Description	Option / Value
Rainfall file organisation and information	IRAINF	File name assigned to daily rainfall/climate data	Lukatola.dat
	PPTCOR	Precipitation adjustment option	0: No adjustment to be made
	FORMAT	Format of daily climate data	Single
	MAP	Mean annual precipitation (mm)	1100
Streamflow file organisation	IOBSTQ	Availability of observed daily streamflow data	No
	IOBSPK	Availability of observed daily peak discharge data	No
	IOBOVR	Option to use observed streanflow data as streamflow input to downstream subcatchments	No
Dynamic file organisation	DYNAMIC	Option to invoke a dynamic input file	No: No dynamic input file to be used
Locality and catchment information	HEAD	General heading of this subcatchment	Kasana
	CLAREA	Area of subcatchment in km^2	10.04
	ELEV	Altitude in metres above mean sea level	1151
	IHEM	Hemisphere indicator	South
	IQUAD	Quadrant indicator	East
	ALAT	Latitude of the centre of subcatchment in degrees and minutes	10 31
	ALONG	Longitude of the centre of subcatchment in degrees and minutes	26 17
Length of record for simulation	IYSTRT	Start year of simulation	01/01/2001
	IYREND	End year of simulation	31/12/2006
Reference potential evaporation control variables	EQPET	Option to specify by which method the daily reference potential evaporation is to be derived	100: Expert system option
	IEIF	Availability of monthly means of evaporation pan equivalent values	Yes
	ILRF	Altitude correction for temperature values	No
	IWDF	Availability of monthly means of daily windrun values	No
	IRHF	Availability of monthly means of daily average relative humidity values	Yes
	ISNF	Availability of monthly means of daily sunshine duration values	No
	IRDF	Availability of mean monthly radiation flux densities	Yes
	IRDF	Availability of daily or monthly values of temperature, and windrun, and relative humidity, and sunshine duration, or incoming solar radiation	No
Reference potential evaporation input information	TMAX	Monthly means of daily maximum temperatures	See Table 2 of Report
	TMIN	Monthly means of daily minimum temperatures	See Table 2 of Report
	E	Monthly totals of A-Pan equivalent evaporation	See Table 2 of Report
	RH	Monthly means of daily average relative humidity	See Table 2 of Report
	PANCOR	Option to request monthly pan evaporation adjusment	1: Adjustment factor to be applied to all evapration values
	CORPAN	Monthly adjustment factor to be applied to evaporation pan data set	1.12
Catchment soils information	PEDINF	Adequacy of soils information	Yes
	ITEXT	Soil texture class	See Appendix B
	PEDDEP	Soil thickness information	See Appendix B
	DEPAHO	Thickness (m) of topsoil	0.35
	DEPBHO	Thickness (m) of subsoil	1.25
	WP1	Soil water content (m/m) at permanent wilting point for the topsoil	0.195
	WP2	Soil water content (m/m) at permanent wilting point for the subsoil	0.195
	FC1	Soil water content (m/m) at drained upper limit for the topsoil	0.313
	FC2	Soil water content (m/m) at drained upper limit for the subsoil	0.313
	PO1	Soil water content (m/m) at saturation for the topsoil	0.468
	PO2	Soil water content (m/m) at saturation for the subsoil	0.468
	ABRESP	Fraction of "saturated" soil water to be redistributed daily from topsoil into subsoil when topsoil is above drained upper limit	0.4
	BFRESP	Fraction of "saturated" soil water to be redistributed daily from subsoil into groundwater store when subsoil is above drained upper limit	0.4
	ICRACK	Option to account for cracking soils	0: No cracking soils
	SMAINI	Initial soil water content for the A horison expressed as a % of PAWC	0
	SMBINI	Initial soil water content for the B horison expressed as a % of PAWC	0
	SWLOPT	Is a statistical analysis of the soil water regime required	No
Catchment land cover information	LCOVER	Option to specify whether manually input or defualt values are to be used	No: Monthly default values to be used
		CROPNO	See Appendix C
	EFRDEP	Effective total rooting depth	1.75
Total evaporation control variables	EVTR	Option to determine how evaporation from the soil surface and from plant tissue are estimated	1: Es and Et are to be estimated as an entity
	FPAW	Do you want to use critical leaf water potential to establish plant water stress	Yes
	CONST	Fraction of plant available water at which plant stress sets in	-1200
	FOREST	Option for enhanced wet canopy evaporation	0: No forest vegetation
	CO2TRA	Option for simulating under enhanced atmospheric CO2 levels	0: No elevated CO2 concentrations
	TMPCUT	Mean temperature threshold for acive plant growth to take place	1
	IUNSAT	Is the unsaturated soil water redistribution to be included in the soil water budgeting	No
Streamflow simulation control varaibles	QFRESP	Stormflow response fraction of the catchment	0.3
	COFRU	Coefficient of the baseflow response	0.007
	SMDDEP	Effective depth of soil to be considered for the calculation of quickflow response	0.5
	IRUN	Should baseflow be included in the simualted runoff statistics	Yes
	ADJIMP	Fraction of catchment occupied by adjunct impervious areas	0
	DISIMP	Fraction of catchment occupied by disjunct impervious areas	0
	STOIMP	Impervoius area's initial abstraction	1
	COIAM	Monthly coefficient of initial abstraction	
	LYSIM	Is generated stromflow to be reinfiltrated	No
Peak discharge control variables	PEAK	Peak discharge option	No
Wetland simulation variables	IVLEI	Option to simulate wetland	No
Shallow groundwater analysis options	IGWATR		No
Irrigation option	IRRIGN		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No

Mid Mofia

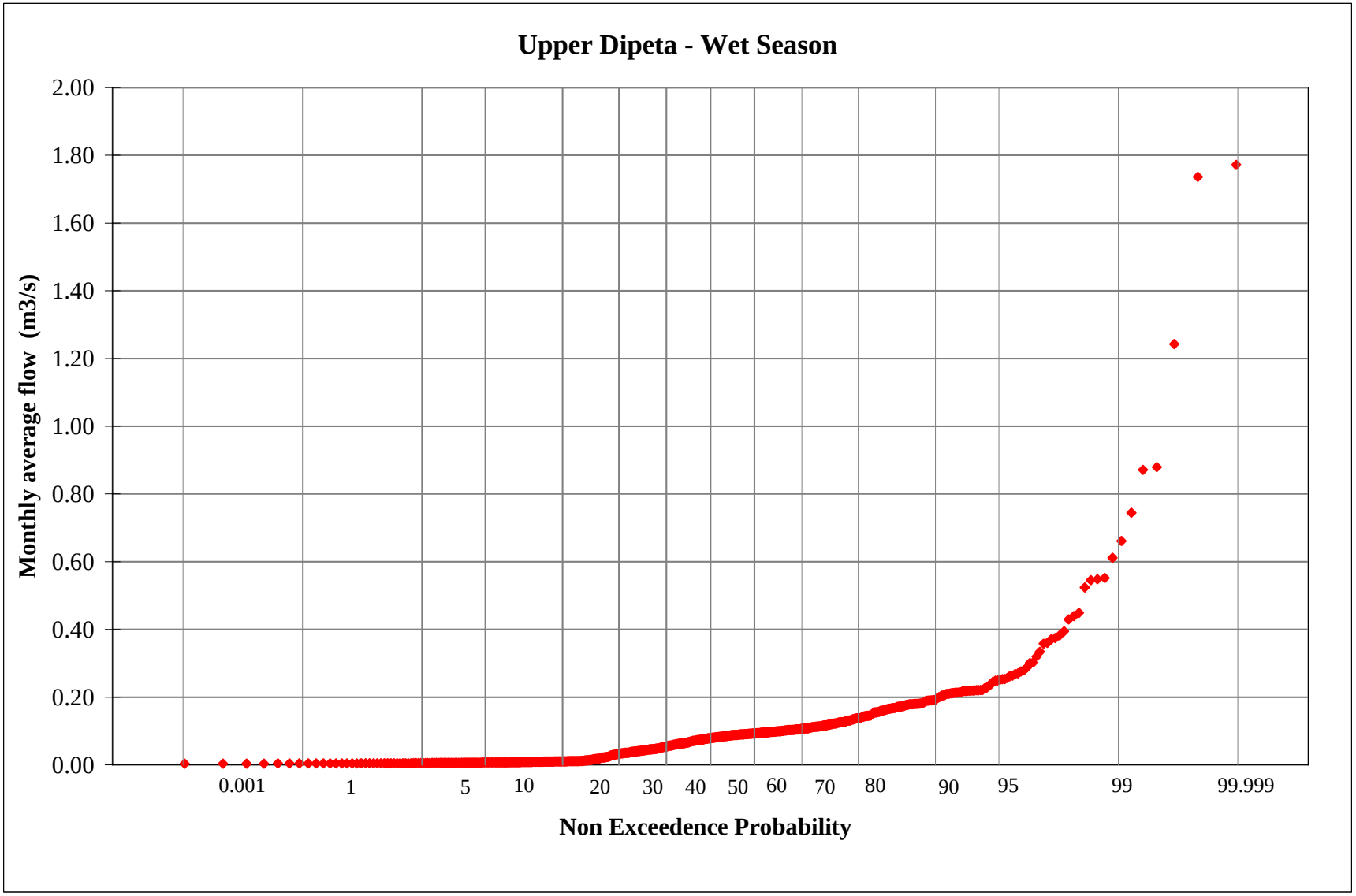
Menu	Variable	Description	Option / Value
Rainfall file organisation and information	IRAINF	File name assigned to daily rainfall/climate data	Lukatola.dat
	PPTCOR	Precipitation adjustment option	0: No adjustment to be made
	FORMAT	Format of daily climate data	Single
	MAP	Mean annual precipitation (mm)	1100
Streamflow file organisation	IOBSTQ	Availability of observed daily streamflow data	No
	IOBSPK	Availability of observed daily peak discharge data	No
	IOBOVR	Option to use observed streanflow data as streamflow input to downstream subcatchments	No
Dynamic file organisation	DYNAMIC	Option to invoke a dynamic input file	No: No dynamic input file to be used
Locality and catchment information	HEAD	General heading of this subcatchment	Mid Mofya
	CLAREA	Area of subcatchment in km^2	59.95
	ELEV	Altitude in metres above mean sea level	1291
	IHEM	Hemisphere indicator	South
	IQUAD	Quadrant indicator	East
	ALAT	Latitude of the centre of subcatchment in degrees and minutes	10 30
	ALONG	Longitude of the centre of subcatchment in degrees and minutes	26 11
Length of record for simulation	IYSTRT	Start year of simulation	01/01/2001
	IYREND	End year of simulation	31/12/2006
Reference potential evaporation control variables	EQPET	Option to specify by which method the daily reference potential evaporation is to be derived	100: Expert system option
	IEIF	Availability of monthly means of evaporation pan equivalent values	Yes
	ILRF	Altitude correction for temperature values	No
	IWDF	Availability of monthly means of daily windrun values	No
	IRHF	Availability of monthly means of daily average relative humidity values	Yes
	ISNF	Availability of monthly means of daily sunshine duration values	No
	IRDF	Availability of mean monthly radiation flux densities	Yes
	IRDF	Availability of daily or monthly values of temperature, and windrun, and relative humidity, and sunshine duration, or incoming solar radiation	No
Reference potential evaporation input information	TMAX	Monthly means of daily maximum temperatures	See Table 2 of Report
	TMIN	Monthly means of daily minimum temperatures	See Table 2 of Report
	E	Monthly totals of A-Pan equivalent evaporation	See Table 2 of Report
	RH	Monthly means of daily average relative humidity	See Table 2 of Report
	PANCOR	Option to request monthly pan evaporation adjusment	1: Adjustment factor to be applied to all evapration values
	CORPAN	Monthly adjustment factor to be applied to evaporation pan data set	1.12
Catchment soils information	PEDINF	Adequacy of soils information	Yes
	ITEXT	Soil texture class	See Appendix B
	PEDDEP	Soil thickness information	See Appendix B
	DEPAHO	Thickness (m) of topsoil	0.35
	DEPBHO	Thickness (m) of subsoil	1.15
	WP1	Soil water content (m/m) at permanent wilting point for the topsoil	0.195
	WP2	Soil water content (m/m) at permanent wilting point for the subsoil	0.195
	FC1	Soil water content (m/m) at drained upper limit for the topsoil	0.313
	FC2	Soil water content (m/m) at drained upper limit for the subsoil	0.313
	PO1	Soil water content (m/m) at saturation for the topsoil	0.468
	PO2	Soil water content (m/m) at saturation for the subsoil	0.468
	ABRESP	Fraction of "saturated" soil water to be redistributed daily from topsoil into subsoil when topsoil is above drained upper limit	0.4
	BFRESP	Fraction of "saturated" soil water to be redistributed daily from subsoil into groundwater store when subsoil is above drained upper limit	0.4
	ICRACK	Option to account for cracking soils	0: No cracking soils
	SMAINI	Initial soil water content for the A horison expressed as a % of PAWC	0
	SMBINI	Initial soil water content for the B horison expressed as a % of PAWC	0
	SWLOPT	Is a statistical analysis of the soil water regime required	No
Catchment land cover information	LCOVER	Option to specify whether manually input or defualt values are to be used	No: Monthly default values to be used
	CROPNO		See Appendix C
	EFRDEP	Effective total rooting depth	1.85
Total evaporation control variables	EVTR	Option to determine how evaporation from the soil surface and from plant tissue are estimated	1: Es and Et are to be estimated as an entity
	FPAW	Do you want to use critical leaf water potential to establish plant water stress	Yes
	CONST	Fraction of plant available water at which plant stress sets in	-1200
	FOREST	Option for enhanced wet canopy evaporation	0: No forest vegetation
	CO2TRA	Option for simulating under enhanced atmospheric CO2 levels	0: No elevated CO2 concentrations
	TMPCUT	Mean temperature threshold for acive plant growth to take place	1
	IUNSAT	Is the unsaturated soil water redistribution to be included in the soil water budgeting	No
Streamflow simulation control varaibles	QFRESP	Stormflow response fraction of the catchment	0.3
	COFRU	Coefficient of the baseflow response	0.006
	SMDDEP	Effective depth of soil to be considered for the calculation of quickflow response	0.5
	IRUN	Should baseflow be included in the simualted runoff statistics	Yes
	ADJIMP	Fraction of catchment occupied by adjunct impervious areas	0
	DISIMP	Fraction of catchment occupied by disjunct impervious areas	0
	STOIMP	Impervoius area's initial abstraction	1
	COIAM	Monthly coefficient of initial abstraction	
	LYSIM	Is generated stromflow to be reinfiltrated	No
Peak discharge control variables	PEAK	Peak discharge option	No
Wetland simulation variables	IVLEI	Option to simulate wetland	No
Shallow groundwater analysis options	IGWATR		No
Irrigation option	IRRIGN		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No

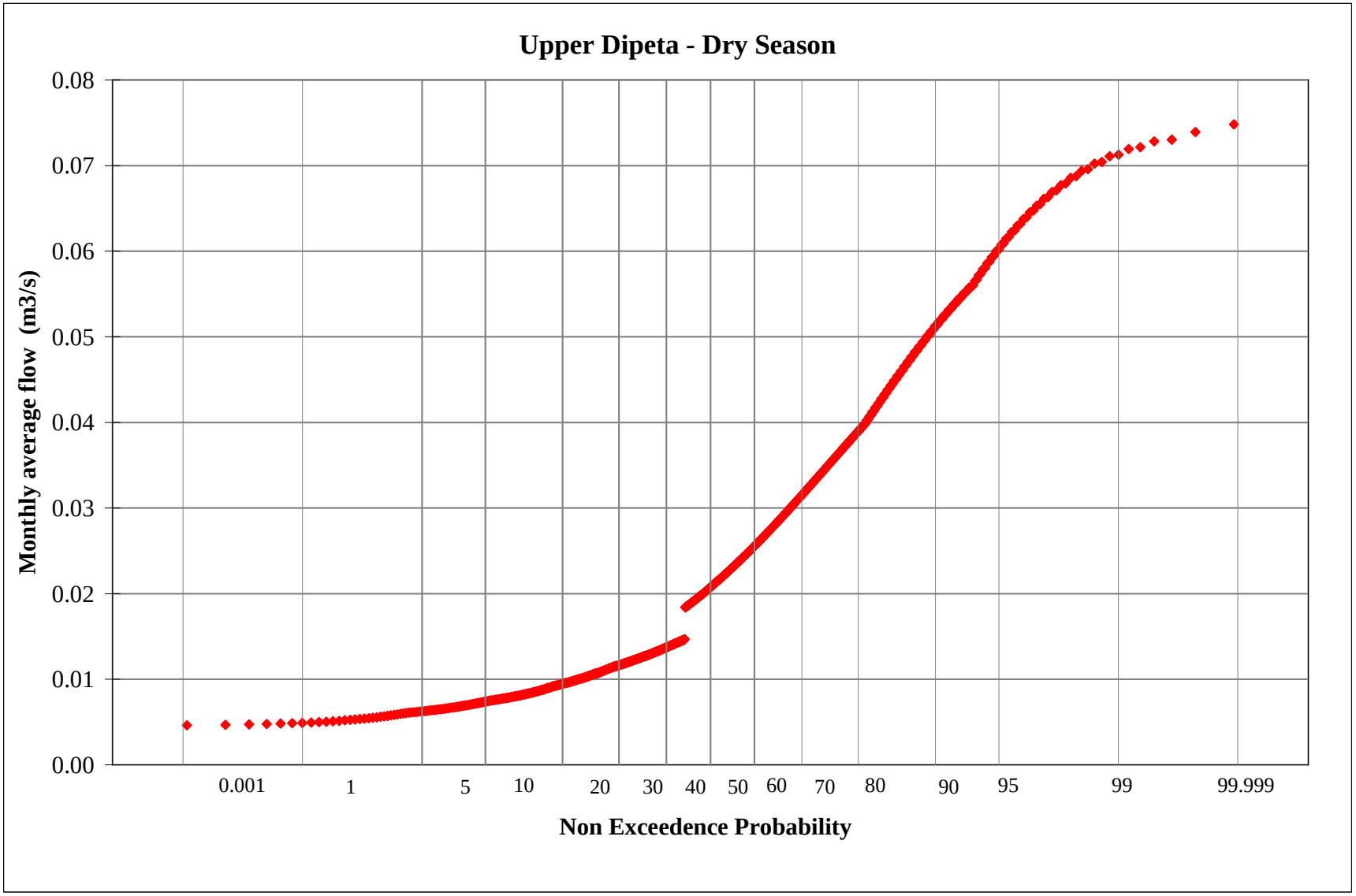
Lower Mofia

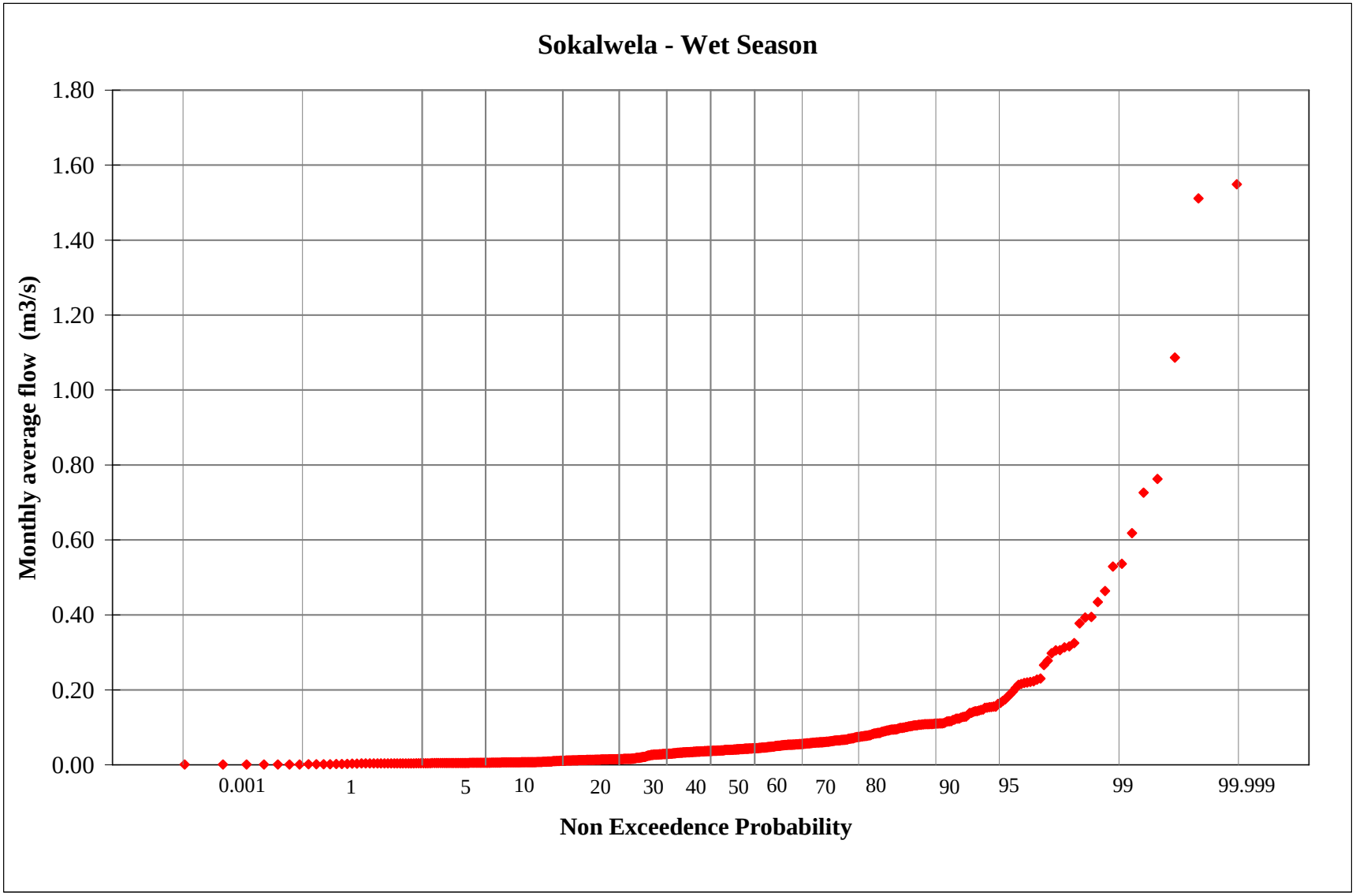
Menu	Variable	Description	Option / Value
Rainfall file organisation and information	IRAINF	File name assigned to daily rainfall/climate data	Lukatola.dat
	PPTCOR	Precipitation adjustment option	0: No adjustment to be made
	FORMAT	Format of daily climate data	Single
	MAP	Mean annual precipitation (mm)	1100
Streamflow file organisation	IOBSTQ	Availability of observed daily streamflow data	No
	IOBSPK	Availability of observed daily peak discharge data	No
	IOBOVR	Option to use observed streanflow data as streamflow input to downstream subcatchments	No
Dynamic file organisation	DYNAMIC	Option to invoke a dynamic input file	No: No dynamic input file to be used
Locality and catchment information	HEAD	General heading of this subcatchment	Lower Mofya
	CLAREA	Area of subcatchment in km^2	168.11
	ELEV	Altitude in metres above mean sea level	1151
	IHEM	Hemisphere indicator	South
	IQUAD	Quadrant indicator	East
	ALAT	Latitude of the centre of subcatchment in degrees and minutes	10 31
	ALONG	Longitude of the centre of subcatchment in degrees and minutes	26 17
Length of record for simulation	IYSTRT	Start year of simulation	01/01/2001
	IYREND	End year of simulation	31/12/2006
Reference potential evaporation control variables	EQPET	Option to specify by which method the daily reference potential evaporation is to be derived	100: Expert system option
	IEIF	Availability of monthly means of evaporation pan equivalent values	Yes
	ILRF	Altitude correction for temperature values	No
	IWDF	Availability of monthly means of daily windrun values	No
	IRHF	Availability of monthly means of daily average relative humidity values	Yes
	ISNF	Availability of monthly means of daily sunshine duration values	No
	IRDF	Availability of mean monthly radiation flux densities	Yes
	IRDF	Availability of daily or monthly values of temperature, and windrun, and relative humidity, and sunshine duration, or incoming solar radiation	No
Reference potential evaporation input information	TMAX	Monthly means of daily maximum temperatures	See Table 2 of Report
	TMIN	Monthly means of daily minimum temperatures	See Table 2 of Report
	E	Monthly totals of A-Pan equivalent evaporation	See Table 2 of Report
	RH	Monthly means of daily average relative humidity	See Table 2 of Report
	PANCOR	Option to request monthly pan evaporation adjusment	1: Adjustment factor to be applied to all evapration values
	CORPAN	Monthly adjustment factor to be applied to evaporation pan data set	1.12
Catchment soils information	PEDINF	Adequacy of soils information	Yes
	ITEXT	Soil texture class	See Appendix B
	PEDDEP	Soil thickness information	See Appendix B
	DEPAHO	Thickness (m) of topsoil	0.35
	DEPBHO	Thickness (m) of subsoil	1.2
	WP1	Soil water content (m/m) at permanent wilting point for the topsoil	0.195
	WP2	Soil water content (m/m) at permanent wilting point for the subsoil	0.195
	FC1	Soil water content (m/m) at drained upper limit for the topsoil	0.313
	FC2	Soil water content (m/m) at drained upper limit for the subsoil	0.313
	PO1	Soil water content (m/m) at saturation for the topsoil	0.468
	PO2	Soil water content (m/m) at saturation for the subsoil	0.468
	ABRESP	Fraction of "saturated" soil water to be redistributed daily from topsoil into subsoil when topsoil is above drained upper limit	0.4
	BFRESP	Fraction of "saturated" soil water to be redistributed daily from subsoil into groundwater store when subsoil is above drained upper limit	0.4
	ICRACK	Option to account for cracking soils	0: No cracking soils
	SMAINI	Initial soil water content for the A horison expressed as a % of PAWC	0
	SMBINI	Initial soil water content for the B horison expressed as a % of PAWC	0
	SWLOPT	Is a statistical analysis of the soil water regime required	No
Catchment land cover information	LCOVER	Option to specify whether manually input or defualt values are to be used	No: Monthly default values to be used
		CROPNO	See Appendix C
	EFRDEP	Effective total rooting depth	1.8
Total evaporation control variables	EVTR	Option to determine how evaporation from the soil surface and from plant tissue are estimated	1: Es and Et are to be estimated as an entity
	FPAW	Do you want to use critical leaf water potential to establish plant water stress	Yes
	CONST	Fraction of plant available water at which plant stress sets in	-1200
	FOREST	Option for enhanced wet canopy evaporation	0: No forest vegetation
	CO2TRA	Option for simulating under enhanced atmospheric CO2 levels	0: No elevated CO2 concentrations
	TMPCUT	Mean temperature threshold for acive plant growth to take place	1
	IUNSAT	Is the unsaturated soil water redistribution to be included in the soil water budgeting	No
Streamflow simulation control varaibles	QFRESP	Stormflow response fraction of the catchment	0.3
	COFRU	Coefficient of the baseflow response	0.006
	SMDDEP	Effective depth of soil to be considered for the calculation of quickflow response	0.5
	IRUN	Should baseflow be included in the simualted runoff statistics	Yes
	ADJIMP	Fraction of catchment occupied by adjunct impervious areas	0
	DISIMP	Fraction of catchment occupied by disjunct impervious areas	0
	STOIMP	Impervoius area's initial abstraction	1
	COIAM	Monthly coefficient of initial abstraction	
	LYSIM	Is generated stromflow to be reinfiltrated	No
Peak discharge control variables	PEAK	Peak discharge option	No
Wetland simulation variables	IVLEI	Option to simulate wetland	No
Shallow groundwater analysis options	IGWATR		No
Irrigation option	IRRIGN		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No
Option for domestic abstractions	IDOMR		No
Resrvoir yield analysis	RESYLD		0: No reservoir yield analysis
Crop yield option	CROP		0: No crop
Frequency analysis: Extreme values	IEVD		No

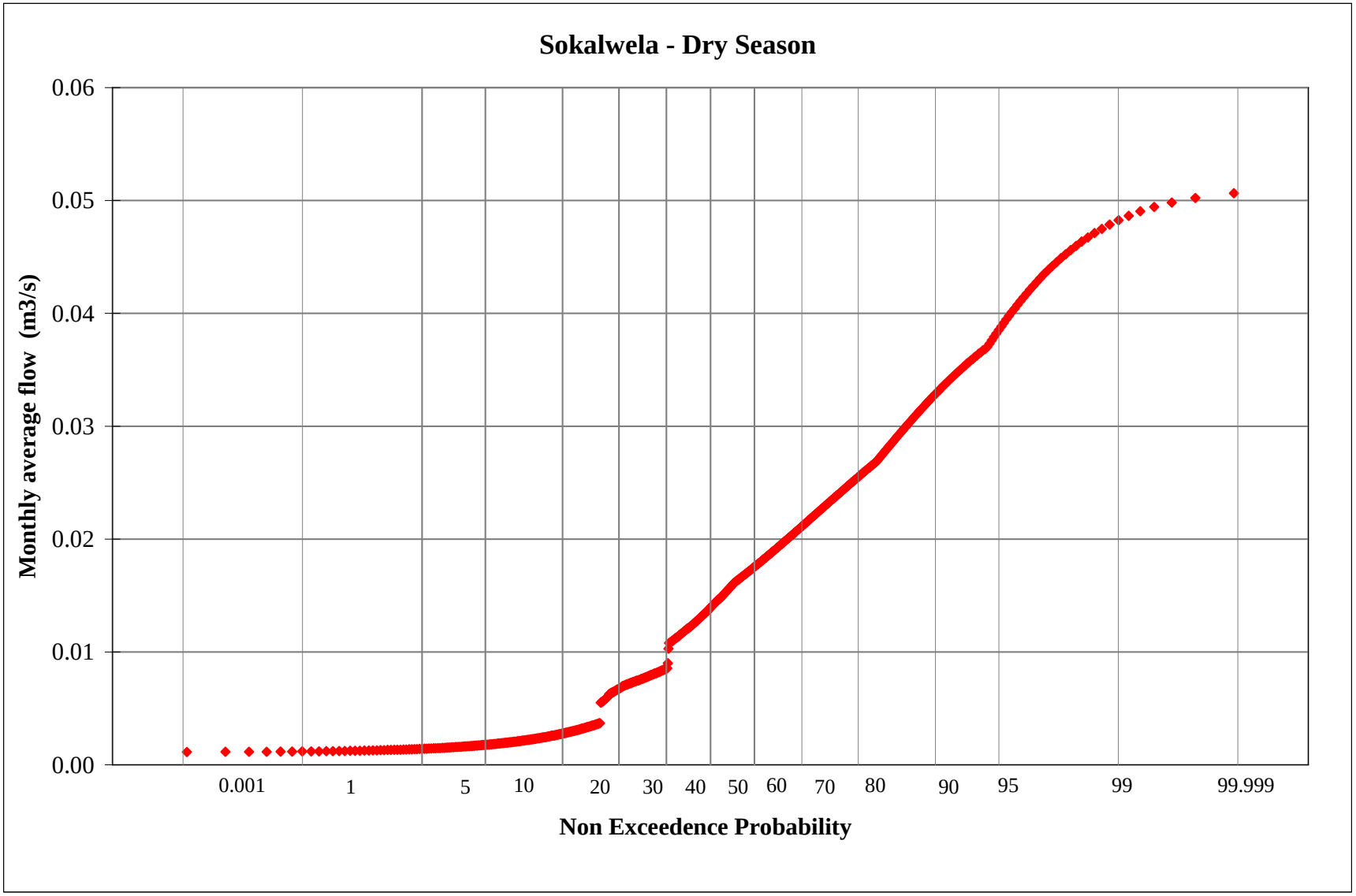
ATTACHMENT 6

FLOW DURATION CURVES OF THE VARIOUS SUBCATCHMENTS

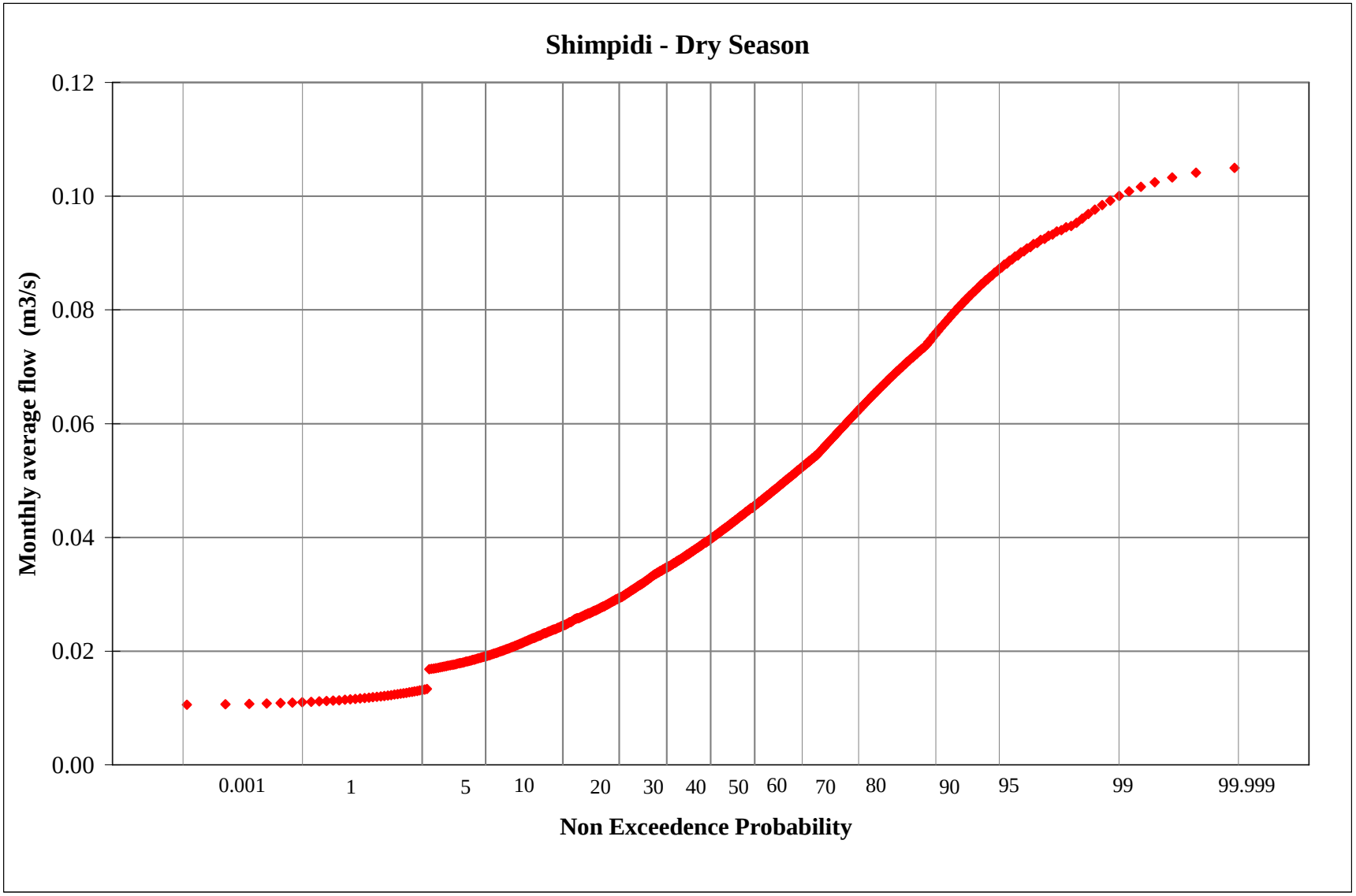

Upper Dipeta - Wet Season
Monthly average flow (m3/s)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability

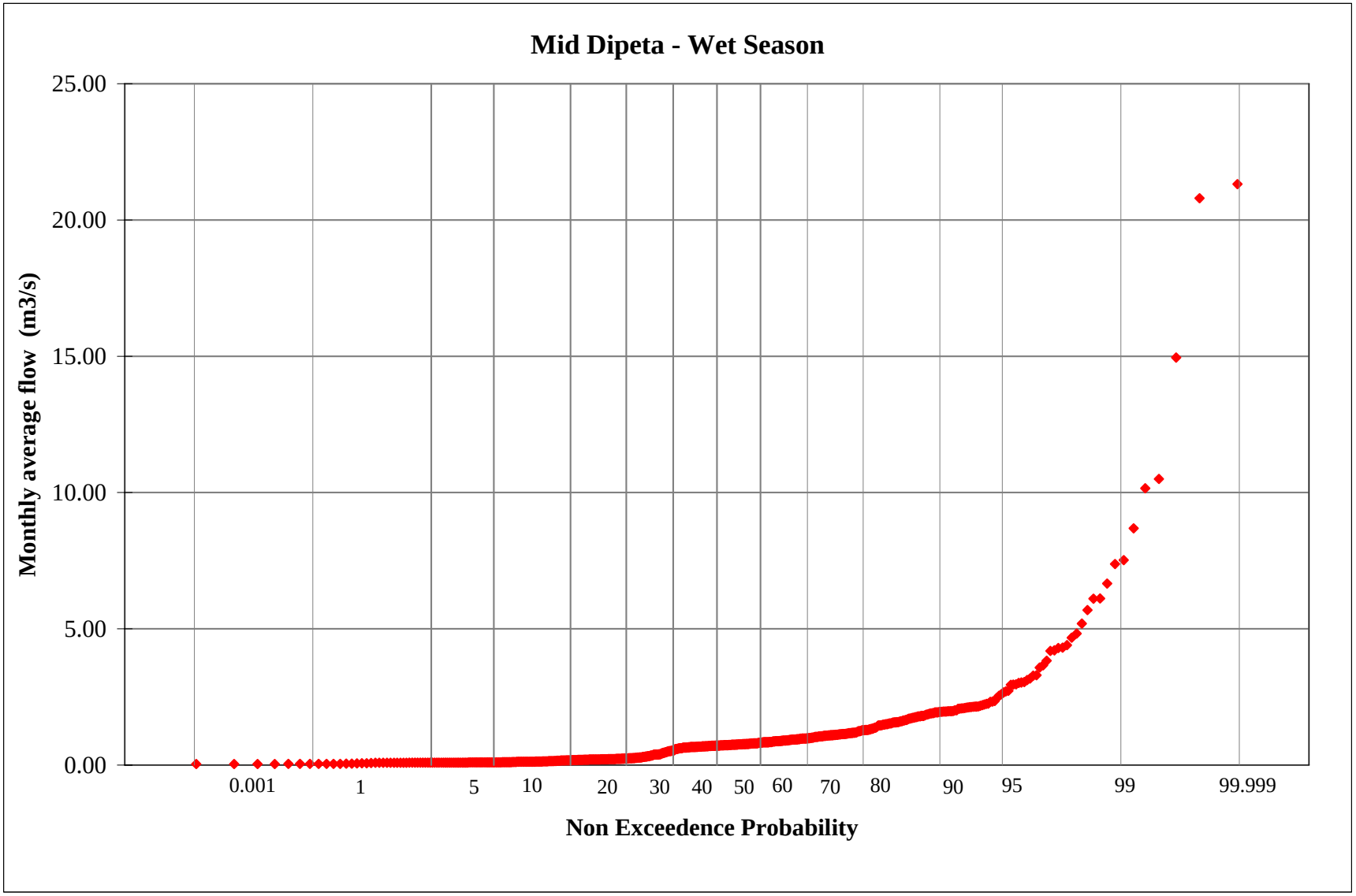

Upper Dipeta - Dry Season
Monthly average flow (m3/s)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability

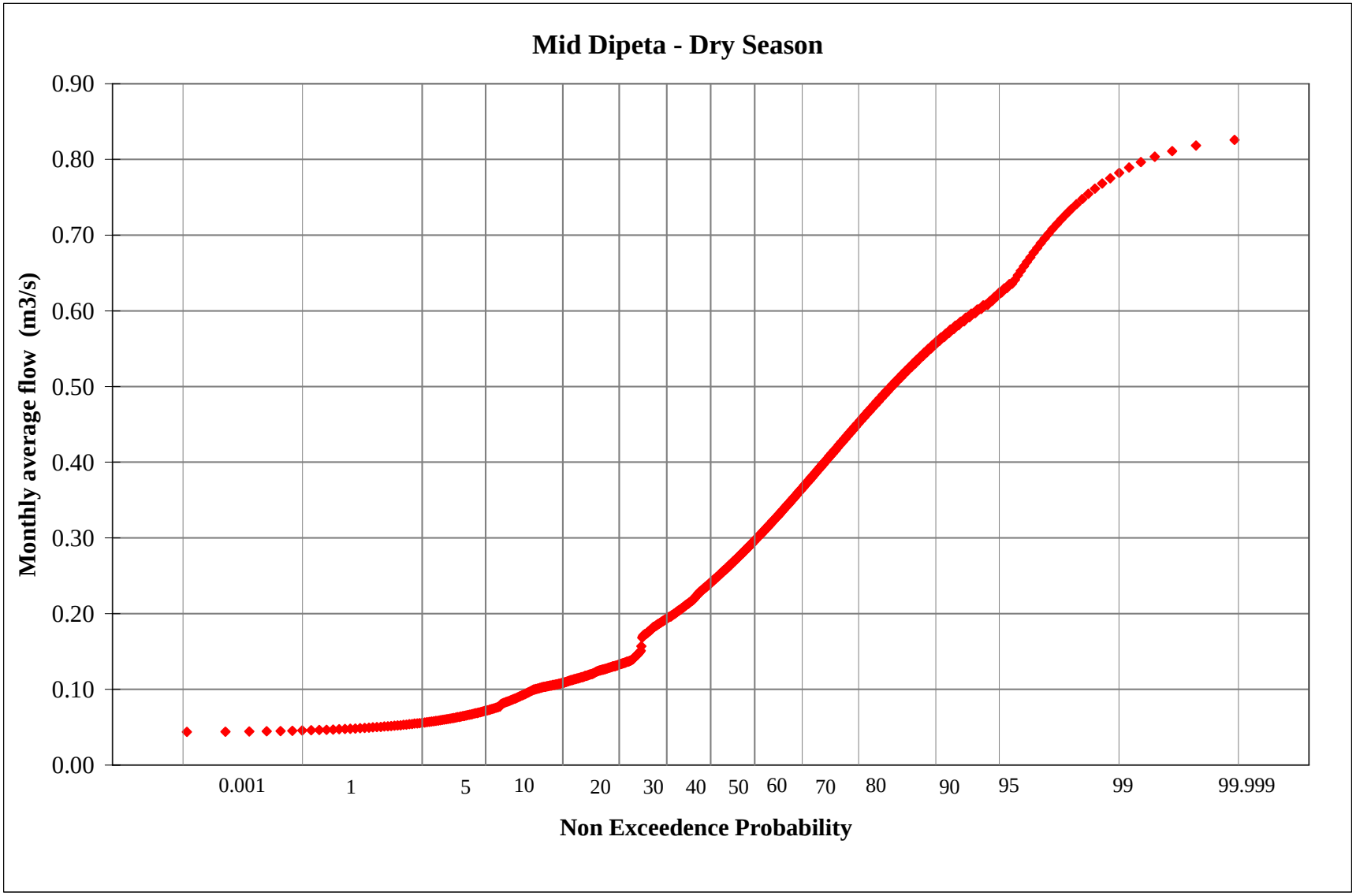

Sokalwela - Wet Season
Monthly average flow (m3/s)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability

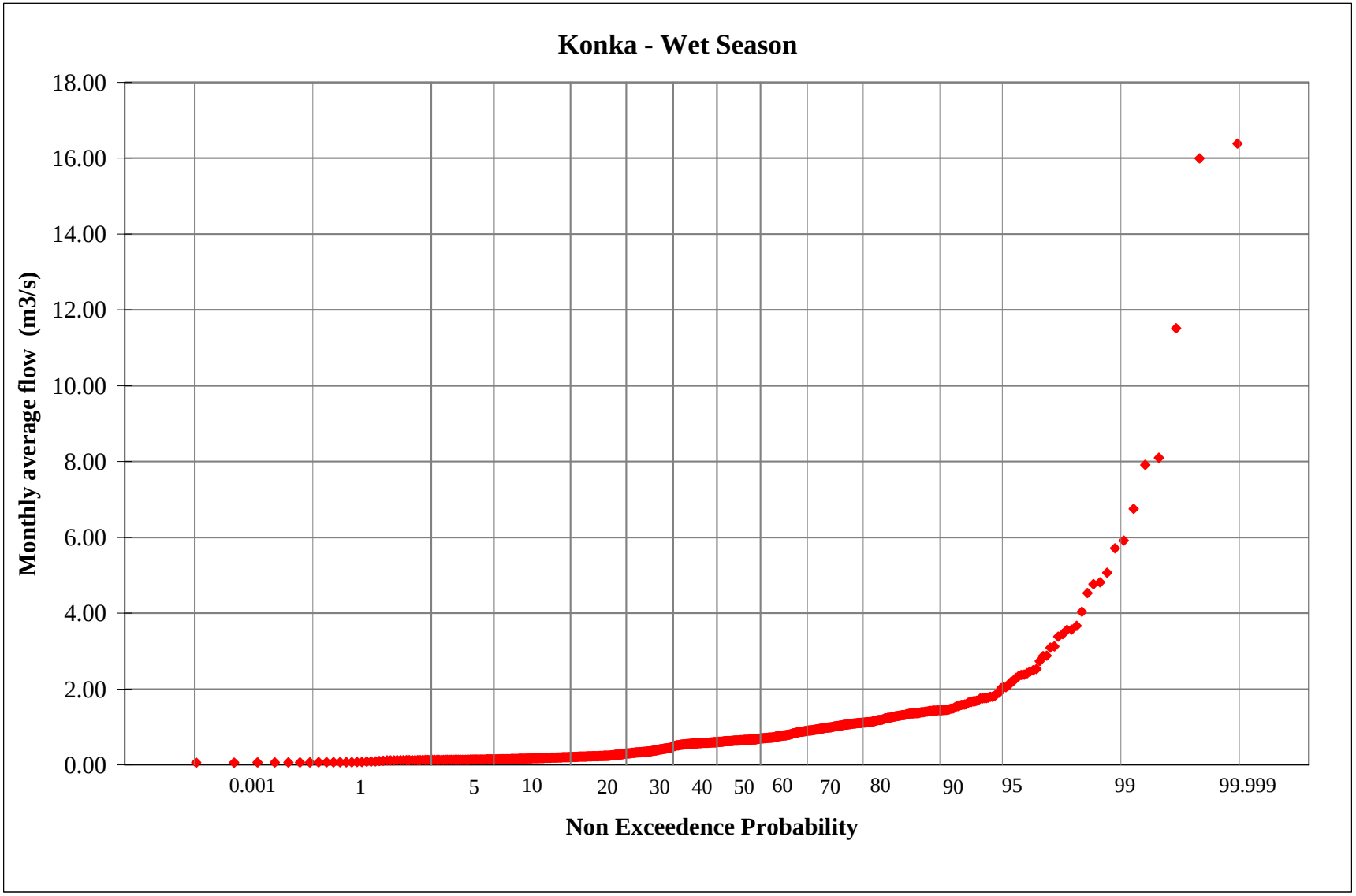

Sokalwela - Dry Season
Monthly average flow (m3/s)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability

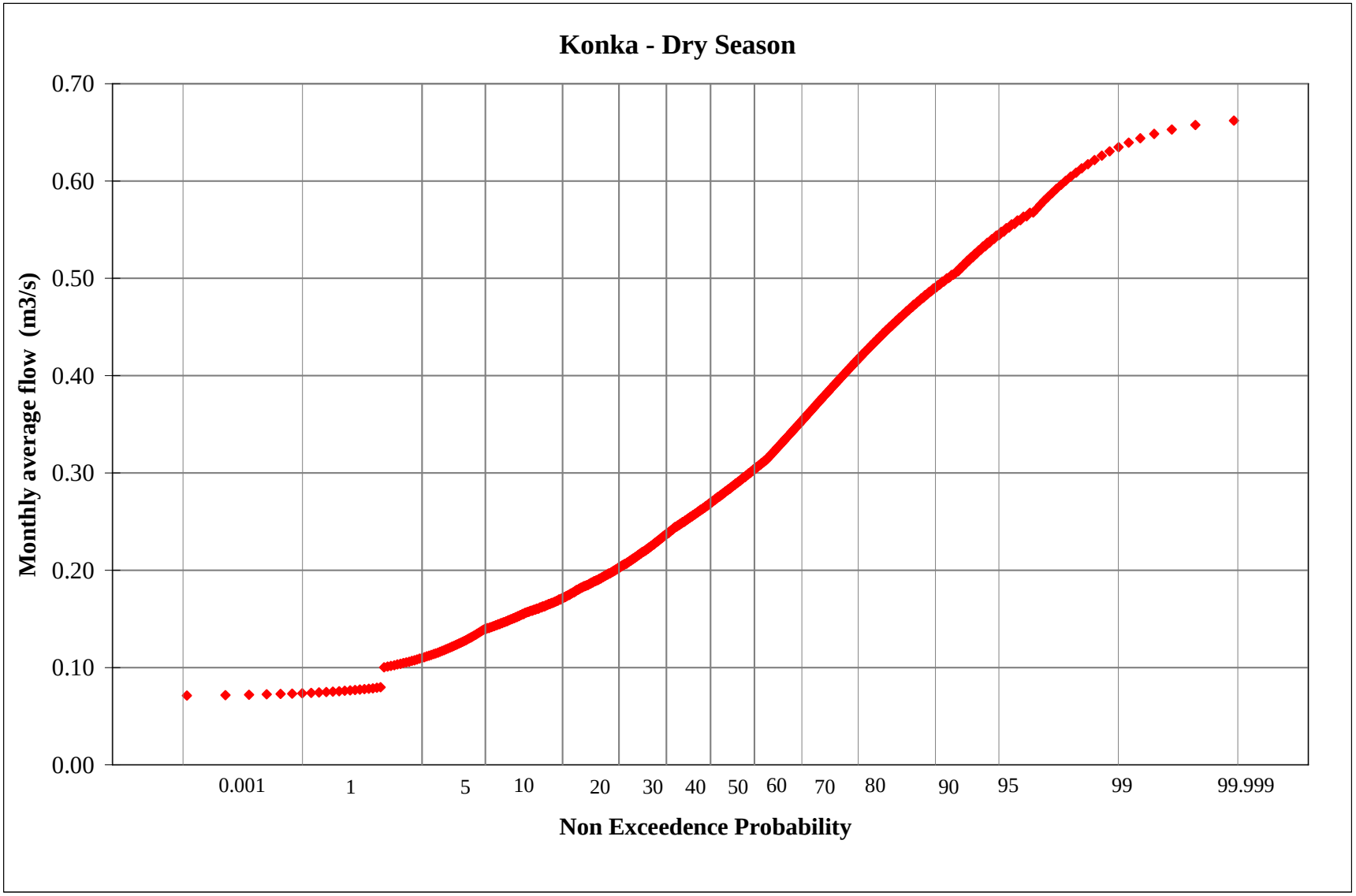
Shimpidi - Wet Season
Monthly average flow (m3/s)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability

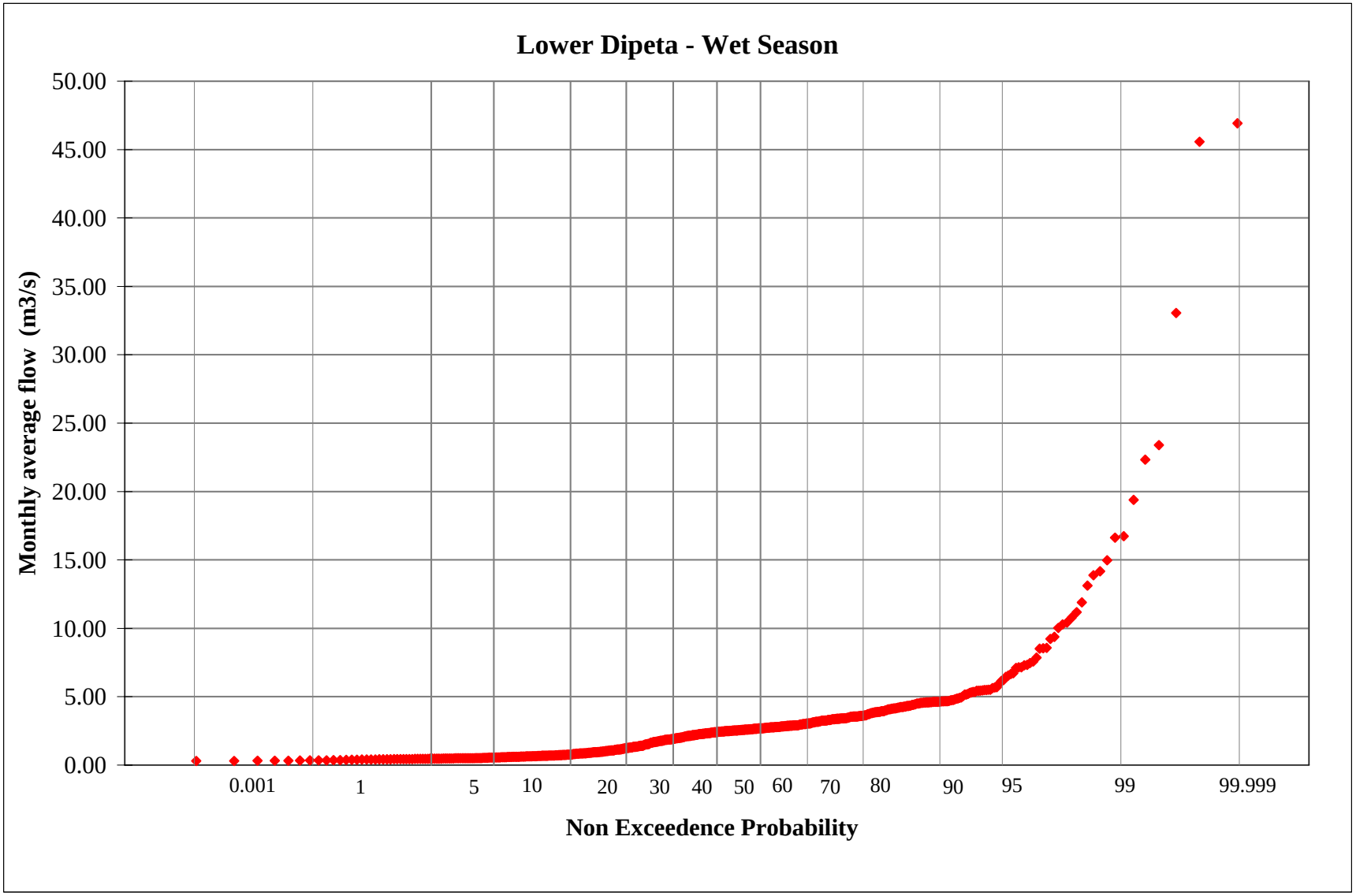

Shimpidi - Dry Season
Monthly average flow (m3/s)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability

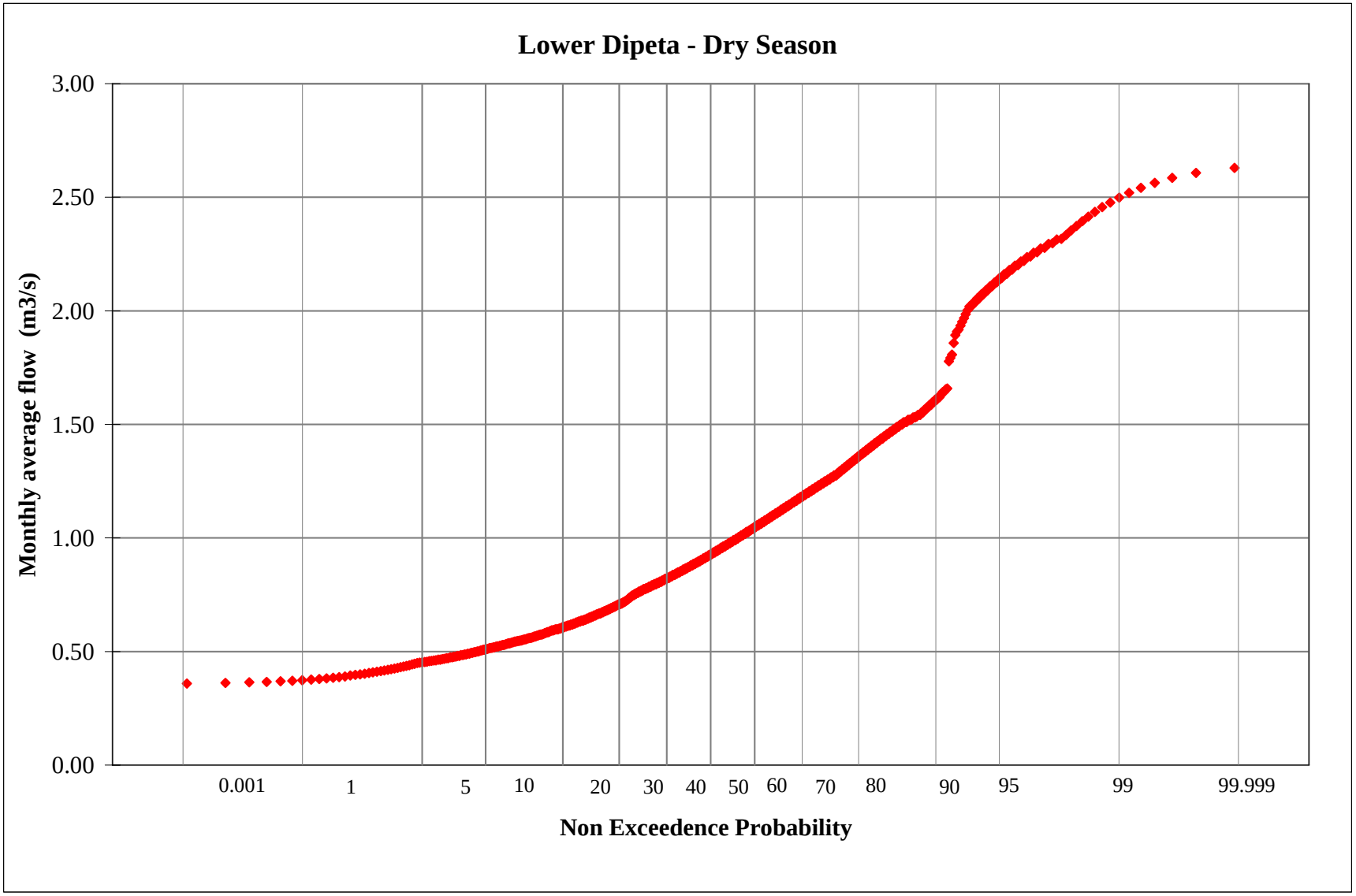

Mid Dipeta - Wet Season
Monthly average flow (m3/s)
25.00
20.00
15.00
10.00
5.00
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability

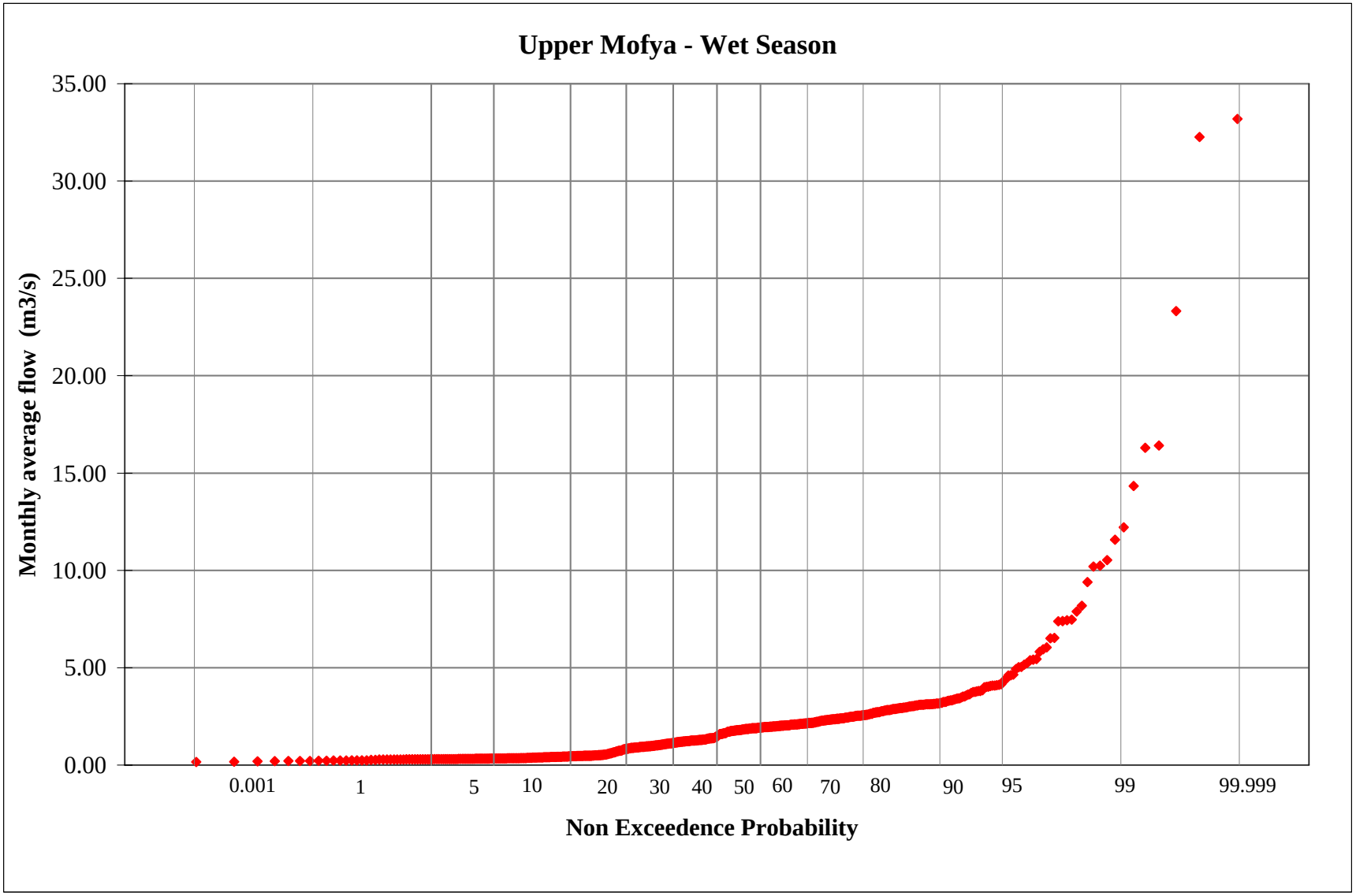

Mid Dipeta - Dry Season
Monthly average flow (m3/s)
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability


Konka - Wet Season
Monthly average flow (m3/s)
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability


Konka - Dry Season
Monthly average flow (m3/s)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability


Lower Dipeta - Wet Season
Monthly average flow (m3/s)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability


Lower Dipeta - Dry Season
Monthly average flow (m3/s)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability


Upper Mofya - Wet Season
Monthly average flow (m3/s)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability

APPENDIX B2.12- I

METHODS FOR THE 1997 AND 1998 WATER QUALITY SURVEY

1 METHODS FOR THE 1997 AND 1998 WATER QUALITY SURVEY

Sampling and data summary for the 1997 and 1998 sampling program was conducted by Golder Associates UK. The purpose of the sampling exercise was to collect data in order to quantify and understand the chemistry of the surface waters in the catchment before the mine is developed. This was achieved by:

- Sampling sufficient locations to quantify the spatial variation in water chemistry.
- Analyzing for parameters that will allow equilibrium modeling of the water chemistry to enhance the understanding of the catchment hydrochemistry.
- Collecting enough samples to quantify any seasonal variation in water chemistry.

1.1 SAMPLING PERIOD

To reflect differences in rainfall, runoff and surface water flow throughout the year, the sampling program was designed around nominal monthly sampling, starting in June 1997 and finishing in May 1998. During early stages of the project, monthly sampling was not always achievable, but in the latter portion of the study period the monthly sampling regime was achieved. To prevent diurnal or weekly variations in water quality affecting seasonal patterns, samples were collected where possible from each location at the same time of the day and same day of the week.

1.2 SAMPLING LOCATIONS

Sampling locations were chosen based on watercourse length, flow, origin and nature of the terrain they flowed through. Particular attention was given to those watercourses which crossed or flowed close to the outcrops of the syncline and other known ore bodies, as it was expected that these might demonstrate elevated metals concentrations as a result of leaching.

The sampling program was concentrated on the Dipeta River and its tributaries, but several additional points were located in the Mafia catchment in order to determine baseline conditions in watercourses which would possibly be impacted by northward flowing runoff from the Kwatebala and Mwinansefu ore bodies.

Sampling locations were located sufficiently far up gradient of stream confluences to ensure that cross contamination during over-bank flooding did not occur. Whenever possible, sampling points were located at bridges in order to make access easier and to minimize the overall sampling time for a particular month. Points were located on the upstream side of each bridge if at all possible, so as to avoid possible contamination from vehicles. The sampling locations are show in Table 1.

Samples were collected from the center of the flow at 60 percent of the flow depth.

1.3 ANALYTICAL PARAMETERS

Parameters analyzed in the sampling program are provided in Table 2. Several analytical parameters were determined in the field: pH, electrical conductance (EC), temperature and dissolved oxygen (DO) were determined with probes directly from the watercourses in slow-moving water.

1.4 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

To avoid cross contamination during the water sampling exercise, new filters were used for each sampling locations, and syringes were washed twice with sample water before use at each sampling location.

To ensure that samples did not become contaminated on site during the sampling exercise, ‘trip’ blanks were prepared using a random selection of sample containers and laboratory-grade water for water sampling. The trip blank was prepared by the laboratory before starting the sampling and was transported around the site in conjunction with other sampling equipment, then submitted for laboratory analysis in conjunction with the recovered samples.

To verify the analytical precision of the methods used by the analytical laboratory, a replicate sample was collected at a single location during each round of sampling, using a Y piece splitter, and submitted for analysis in conjunction with the rest of the samples. The replicated sampling location was chosen at random and varied between sampling rounds, and the samples were not labeled in a manner which indicated they were replicate samples. One inter-laboratory replicate samples was also collected as a check on the analytical accuracy of the laboratory and submitted to a National Accreditation of Measurement and Sampling (NAMAS) accredited laboratory in the United Kingdom for analysis.

Table 1 Water Sampling Point Locations as Described in Field Notes

Point	UTM Easting	UTM Northing	Description
1	423696	828162	borehole P3
4	427270	826016	R. Kalengile dells side of bridge on Likasi road, E. of Fungurume
5	426282	827153	R. Dipeta dells side of bridge on airport road in Fungurume
6	417812	823072	R. Kalumaziba/Konka u/s side of bridge on Kolwezi road
7	413805	828596	R. Shimbidi dells side of bridge near Mwadinkomba II
8	414571	827772	R. Shimbidi dells side of old bridge at Kwatebala village
9	417028	826800	R. Dipeta u/s side of bridge
10	418851	827112	R. Kalumaziba/Konka dells side of bridge, just above confluence with R. Dipeta
11	414929	826113	R.? dells side of bridge near Kansalawile F
12	417612	825659	R Kalumaziba dells side of bridge near Mambilima A
13	422023	824407	R. Kamwezi u/s side of bridge on Kolwezi road
14	42008	827493	R. Dipeta dells side of new bridge W of Mwela Mpande village
15	422222	826891	R. Dipeta dells side of heavy duty bridge S of Mwela Mpande village
16	423936	826252	R. Dipeta dells side of 'first' (knackered) bridge near Trabeza camp
17	409996	829274	small stream tributary of R. ? in Mofia catchment, N of Winanswefu
18	405187	828050	R. Dipeta u/s side of bridge near Tenke
19	409722	828062	stream in dembo SW of Kwatebala hill, u/s side of bridge
20	423163	825825	R. Kamwezi u/s side of bridge near 'Native' camp, u/s of confluence with R. Dipeta
21	415891	828563	spring/stream on Shadzironzoro near Kwatebala village
22	424625	823764	R. Kalengile u/s side of bridge above Kalengile wetland area, behind hill S of Trabeza
23	416610	822548	spring from Zakeo, just north of Kolwezi road, near Kafwaya village
24	413535	824452	stream near Kachimilombe
25	413223	823862	stream near Zikulel/Kachimilombe
26	427531	826157	R. Dipeta 40 meters dells of confluence with R. Kalengile near Likasi road, E of Fungurume
27	426546	825306	R. Kalengile u/s side of knackered bridge on S edge of Fungurume
28	426250	825102	R. Kalengile dells side of railway bridge at exit from Kalengile wetland
29	422139	826406	Wadi crossing road ascending to Hill 5 (Fungurume hill)
30	419792	828151	low point of dembo on road midway between 'crossroads' and Mwela Mpande village
31	413071	825615	small channel in dembo near Kachimilombe XI
32	410854	827456	R. Dipeta in dembo near Kansalawile
33	407963	827664	R. Dipeta u/s side of bridge in dembo near Katuto
34	416085	828049	stream dells side of bridge between Kwatebala village and 'crossroads'
35	417520	831950	stream flowing to Mofia near north road near Ndela village
36	408179	833475	stream flowing to Mofia on track north of Kavifwafwaulu

Table 1 Water Sampling Point Locations (continued)

Point	UTM Easting	UTM Northing	Description
37	409780	834736	stream flowing to Mofia far North of Winansefu
38			n/a
39			n/a
40	404904	829413	spring to NE of Tenke, N of SP18
41	427720	826205	Dipeta E of Fungurume, upstream of tailings dam, downstream of 26
42	432923	831238	Dipeta to E of tailings dam, downstream

Table 2 Wells

Point	UTM Easting	UTM Northing	Description
101	425835	826670	50 m before main railway line towards airport, RHS of road
102	425980	826978	50 m after second crossing of main line, small lane on LHS. 80 m towards river, on LHS of lane
103	426372	827173	80 m after Dipeta bridge towards airport, next to church on RHS
104	426213	827228	150 m of Dipeta Bridge, road on LHS, 120 m to end of road, left, well 40 m on RHS
105	426227	826876	towards airport, large road joining obliquely before market on RHS, 80 m from airport road, well on LHS
106	426148	826720	continue from 105. 60 m before edge of built-up area, on LHS opposite shop
107	426356	825797	RHS of Likasi road 100 m E from railway crossing, almost opposite large road to market
108	426560	825900	further toward Likasi, 200 m from railway, 60 m from road on LHS then left
109	426721	825902	further toward Likasi 80 m from edge of town on RHS
110			n/a
111	403735	828130	Tenke -tap to W of main NS road (pumped from Tshilongo)
112	404056	827968	Tenke -well in center of village, 200 m N of main EW road

UTM = universal transvere mercator.
R. = river.
u/s = upstream.
LHS = left-hand side.
RHS = right-hand side.
n/a = not applicable.

Table 3 Parameters Analyzed in the 1997 and 1998 Sampling Program

Parameter
Major Ions
sodium
potassium
calcium
magnesium
chloride
sulfate
silica
Nutrients
ammoniacal nitrogen
nitrite
nitrate
phosphate
Metals
manganese
aluminum
total iron
arsenic
cadmium
nickel
lead
copper
chromium
mercury
zinc
cobalt
Other
iron (III)
bicarbonate
carbonate

An additional method used to estimate sampling errors was the production of a field duplicate sample during each round of sampling. Duplicates were produced by repeating the sampling procedure at a randomly selected location. The samples were not labeled in a manner which indicated they were duplicate samples.

All samples collected were accompanied by a Chain of Custody Record sheet, which was completed and returned to Golder Associates UK with the analytical data. The record sheet was checked to verify that:

- Sampling has been done according to specification.
- Samples have been transported to the laboratory within the nominated time frame.
- Samples have, if necessary, been preserved.
- Analysis has been completed within the specified time frame.

Each sample was given a unique sample identification number on site. Each sample container was clearly marked with this number, analytical requirements, preservation technique used, and the submitting organization, i.e., Golder Associates UK.

Once the draft data was received from the testing laboratories it was subjected to a series of quality control checks, including:

1. Blank samples were used to prepare site-specific detection limits rather than those quoted by the analytical laboratory.
2. The results of duplicate sampling were used to estimate errors due to sampling.
3. The results of replicate sampling were used to estimate analytical errors. If analytical errors appeared, excessive results of the relevant laboratory checking program were examined.
4. Once errors due to analytical or sampling had been estimated confidence limits were calculated. These limits were then applied to the remaining data to identify data falling outside the limits. Such 'outliers' were checked, firstly from the raw data retained by the laboratory and then, if necessary, by reanalyzing the sample.
5. An anion: cation balance was calculated for each of the water samples as a check that all major analytes had been included in the analytical suite and that results were accurate.

Once the data had been subjected to the above checks and had passed satisfactorily, data analysis began.

Several analytical parameters were determined in the field, since samples tend to destabilize with time. PH, electrical conductance (EC), temperature and dissolved oxygen (DO) were determined with probes directly from the watercourses. Small

samples were taken for analysis of turbidity on the bank, by means of a turbidity meter. These readings provide valuable data, and help in the interpretation of analytical results.

Care was taken to handle, use and store the meters and probes in accordance with manufacturers' instructions. PH and EC meters were of the self-compensating type, i.e., they adjusted readings to take account of water temperature. These probes were, however, calibrated at the start and end of each day by means of manufacturers' calibration buffer solutions at known temperatures. The DO meter and probes were calibrated at intervals as specified by the manufacturer with supplied equipment. Before readings were taken, probes were thoroughly washed, then allowed to equilibrate with the water until their readings stabilized.

Meters used were as follows:

temperature	Whatman digital probe thermometer, -20 to +150 degrees Celcius range, 0.1 degrees Celcius resolution.
electrical conductivity	Whatman digital temperature-compensated pocket unit, 10-1990 microseimens per centimeter (µS/cm) range, 10 µS/cm resolution.
pH	Whatman digital temperature-compensated pocket unit, 0.0 - 14.0 pH range, 0.1 pH resolution.
turbidity	ELE digital Turbidimeter, 0 - 50 NTU range, 5 percent resolution.
dissolved oxygen	ELE digital dissolved oxygen/temperature meter, 0.0 - 19.9 milligrams per liter range, 0.1 milligrams per liter resolution.

APPENDIX B2.12- II

PHOTOGRAPHS OF 2006 WATER QUALITY SAMPLING LOCATIONS

Photograph 1 Site SW1, Upper Dipeta River, Northeast of Tenke

Photograph 2 Site SED 2, Kazakenene River Western Tributary Stream Sediment

Photograph 3 Site SW4a, Kasana River (Upper Reaches)

Photograph 4 Site SW4b, Kasana River (Upper Reaches)

Photograph 5 Site SW6, Unnamed Tributary to Kasana River Near Mulumbu

Photograph 6 Site SW7, Kazakenene River Mid-Stream

Photograph 7 Site SW8, Mofia River Upstream of Kazakenene River Confluence

Photograph 8 Site SW9, Mofia River Between Kazakenene and Kasana Confluences

Photograph 9 Site SW10, Sokalwela River, Downstream of Kwatebala Deposit

Photograph 10 Site SW11, Dipeta River, Below the Confluence with the Shimbidi River

Photograph 11 Site SW12, Dipeta River, Below the Confluence with the Sokalwela River

Photograph 12 Site SW13, Kalengmlawa River North of the Railway Line

Photograph 13 Site SW14, Kakapidi River Before the Confluence with the Dipeta River

Photograph 14 Site SW15, Dipeta River Between the Kakapidi and Konka River Confluences

Photograph 15 Site SW16, Konka River Before the Confluence with the Dipeta River

Photograph 16 Site SW17, Mofia River Downstream Sample

Photograph 17 Site SW18, Dipeta River Downstream Sample Taken at Fungurume

APPENDIX B2.12-III

BACKGROUND GENERAL WATER QUALITY INFORMATION

Background General Water Quality Information

Introduction

Baseline water quality from 2006 in surface waterbodies was described in terms of key physical and chemical characteristics. This report focuses on parameters that are considered indicators of important aspects of water quality including pH, dissolved oxygen, major ions, acid sensitivity, total suspended solids (TSS), nutrients and metals. A brief description of key water quality parameters used in this report is presented below.

pH

The pH is an indication of the acidic or basic (i.e., alkaline) nature of water. Neutral water has a pH of seven. The pH of natural surface waters is commonly between six and nine. Most aquatic organisms can tolerate waters that fall within this pH range. If water becomes more acidic, the pH drops. If water becomes more alkaline, the pH increases. Acid deposition, resulting from anthropogenic (man-made) air emissions, can lower the pH of surface waters.

Dissolved Oxygen

Dissolved oxygen is a measure of the amount of gaseous oxygen, (i.e., O_2) dissolved in water. Dissolved oxygen levels are governed by a balance between inputs from the surrounding air, aeration (i.e., rapid movement), and as a product of photosynthesis and losses from chemical and biotic oxidations. The amount of oxygen available to aquatic life depends on the solubility of oxygen, which is governed by atmospheric pressure, turbulence, temperature, salinity, currents, ice-cover and biological processes (Wetzel 2001). Reduced oxygen levels can cause physiological and behavioral effects in aquatic organisms. In this report, dissolved oxygen concentrations are compared to the aquatic life guidelines.

Major Ions

Three indicators related to the concentrations of major ions in surface waters are hardness, total dissolved solids (TDS) and conductance.

The toxicity of many metals declines with increasing hardness, which is a measure of the sum of calcium and magnesium concentrations. Table 1 provides a general scale of water hardness, expressed as milligrams per liter (mg/L) equivalent of calcium carbonate.

Table 1 Qualitative Scale of Water Hardness Based on Calcium Carbonate

Hardness Scale	Calcium Carbonate (mg/L)
very soft *(low)*	0–30 *(<28)*
soft	31–60
moderately soft *(relatively low)*	61–120 *(28–120)*
hard	121–180
very hard	>180

Note: Italics indicate definitions of hardness by Mitchell and Prepas (1990).
Sources: McNeely et al. (1979); Mitchell and Prepas (1990).

Another measure of the amount of major ions in water is TDS, which is the concentration of dissolved salts remaining after filtered water is evaporated at 180 degrees Celsius. Total dissolved solids in excess of 1,000 milligrams per liter can adversely affect freshwater aquatic life (Hart et al. 1990). Table 2 provides a scale of TDS and salinity.

Table 2 Qualitative Scale of Salinity Based on Total Dissolved Solids

Salinity Scale	Total Dissolved Solids (mg/L)	Salinity (parts per thousand)
fresh water	<500	<0.5
slightly saline	500–1,000	0.5–1
moderately saline	1,000–5,000	1–5
saline	>5,000	>5

Source: Mitchell and Prepas (1990).

Electrical conductance is another measure of the total quantity of dissolved ions in water. Conductance and TDS are strongly correlated. Table 3 provides the qualitative scales for TDS and conductance in fresh water. Table 4 provides the qualitative scale for TDS in groundwater. Groundwater generally has higher major ions concentrations than surface water and therefore, the scales differ.

Table 3 Qualitative Scales of Total Dissolved Solids and Conductance in Fresh Water

Description	Total Dissolved Solids (mg/L)	Conductance (µS/cm)
low	≤100	≤165
moderately low	101–200	166–330
moderate	201–300	331–500
moderately high	301–400	501–665
high	401–500	666–830
very high	>500	>830

Table 4 Qualitative Scale of Total Dissolved Solids in Groundwater

Description	Total Dissolved Solids (mg/L)
Fresh	≤1000
Brackish	1001–10,000
Saline	10,001–100,000
Brine	>100,000

Source: Fetter (2001)

Acid Sensitivity

Alkalinity is a measure of the acid neutralizing capacity (ANC) of water and provides an indication of the sensitivity of water to acid deposition. Saffran and Trew (1996) presented a scale of lake sensitivity to acidification based on alkalinity (see Table 5).

Table 5 Qualitative Scale of Lake Acid Sensitivity

Acid Sensitivity	Alkalinity	
	(mg/L $CaCO_3$)	(µeq/L)
high	0–10	0–200
moderate	10–20	200–400
low	20–40	400–800
least	>40	>800

Source: Saffran and Trew (1996).

The commonly accepted categories of acid sensitivity for streams, provided in Table 6, are based on alkalinity and ANC. An annual average value of 150 microequivalents per liter has also been used as a cut-off point for

designating streams as acid sensitive, based on effects on fish populations in streams with ANC above microequivalents per liter (Brewer et al. 2000).

Table 6 Qualitative Scale of Stream Acid Sensitivity

Acid Sensitivity	Alkalinity (mg/L as $CaCO_3$)	Acid Neutralizing Capacity (meq/L)
acidic	<0	<0
highly sensitive	0–2.5	0–50
sensitive	2.6–10	51–200
not sensitive	>10	>200

Source: Boward et al. (1999).

Total Suspended Solids

Total suspended solids, also referred to as total suspended sediment, includes all particles suspended in the water column that would be removed using a filter with pore sizes of 0.45 microns. An increase in TSS can result in stress to aquatic animals. Total suspended solids concentrations below 25 milligrams per liter are usually not considered harmful to aquatic life (Department of Fisheries and Oceans Canada [DFO] and Department of Environment [Environment Canada] [DOE] 1983; European Inland Fisheries Advisory Commission [EIFAC] 1965; United States Environment Protection Agency [US EPA] 1973). The nature and severity of adverse effects of TSS is a function of concentration and exposure. Most aquatic organisms can withstand high levels of TSS for short periods and low levels for long periods (Newcombe and MacDonald 1991). Total suspended solids categories used in this report are:

- Low – less than 10 milligrams per liter.
- Moderate – 10 to 25 milligrams per liter.
- High – greater than 25 milligrams per liter.

Nutrients

Nutrients include nitrogen and phosphorus compounds that are required in small quantities for plant growth. In general, the biological productivity of fresh water is limited by phosphorus, meaning that phosphorus is the nutrient in the shortest supply. Total phosphorus concentrations can range from 1 microgram per liter in unproductive waters to greater than 100 micrograms per liter in highly productive waters. Table 7 presents a trophic-based (i.e., nutrient-related), classification of lakes and rivers in relation to phosphorus concentrations.

Table 7 Trophic Classification of Lakes and Rivers Based on Total Phosphorus Concentration

Trophic Status	Total Phosphorus (mg/L)	
	Lakes[(a)]	Rivers and Streams[(b)]
ultra-oligotrophic (very nutrient-poor)	<0.004	–
oligotrophic (nutrient-poor)	0.004–0.01	<0.025
mesotrophic (containing a moderate level of nutrients)	0.01–0.02	0.025–0.075
meso-eutrophic (containing moderate to high level of nutrients)	0.02–0.035	–
eutrophic (nutrient rich)	0.035–0.1	>0.075
hypereutrophic (very nutrient rich)	>0.1	–

(a) Vollenweider and Kerekes (1982).
(b) Dodds et al. (1998).
– = Not applicable.

Metals

Metals occur naturally in small quantities, i.e., less than 1 milligram per liter, in surface waters. Higher metal concentrations are usually associated with suspended sediments and tend to settle out. Elevated levels of metals can affect aquatic organisms. The level at which metals are toxic varies by metal and can be dependent on many factors including hardness, dissolved organic matter (DOC), pH and redox conditions. Dissolved metals refer to the portion of the metals that are dissolved in the water column (i.e., would not be filtered out in analysis) and tend to be more bio-available than metals adsorbed to particulates. Total metals refers to the sum of dissolve and particulate metals and is the form analyzed in this report.

Narrative Guidelines

Narratives for US EPA guidelines for the protection of aquatic life are as follows:

- US EPA Hardness guideline - The US EPA narrative states that the effects of hardness on freshwater fish and other aquatic life appear to be related to the ions causing the hardness rather than hardness. US EPA recommended against the use of the term hardness but suggest the inclusion of the concentrations of the specific ions (US EPA 1986). It has been suggested that aquatic organisms may respond differently to different TDS compositions with relative ion toxicity was, in decreasing, order: potassium, bicarbonate, magnesium, chloride and sulphate (Mount et al. 1997). Compared on the basis of chloride, the chlorides of potassium, calcium, and magnesium are generally more acutely toxic to aquatic animals than sodium chloride (US EPA 1988).
- Dissolved oxygen guideline for warm water biota:

  - Early life stages = 6 milligrams per liter (7-day mean), 5.0 milligrams per liter (1-day minimum).
  - Other life stages = 5.5 milligrams per liter (30-day mean), 4.0 milligrams per liter (7-day mean minimum), 3.0 milligrams per liter (1-day minimum).

- Temperature guideline: Species-specific maximum temperature exposure for a short time. Values are provided in EPA 440–5–86–001 Quality Criteria for Water 1986 (Gold Book) (US EPA 1986).
- Color guideline: Waters shall be virtually free from substances producing objectionable color for aesthetic purposes. Increased color (in combination with turbidity) should not reduce the depth of the compensation point for photosynthetic activity by more than ten percent from the seasonally established norm for aquatic life.
- Suspended solids and turbidity guideline: Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than ten percent from the seasonally established norm for aquatic life (for solids – suspended, settleable and turbidity).
- Total phosphorus guideline - The US EPA has developed region-specific criteria for nutrients and corresponding response variables, which are intended to form a starting point to develop more refined nutrient criteria, as appropriate, using EPA waterbody–specific technical guidance manuals and other scientifically defensible approaches (US EPA 2002). These guidelines would not generally be applicable to the study location.
- Oil and grease guideline: 0.01 of the lowest continuous flow 96-hour LC50 to several important freshwater and marine species, each having demonstrated high susceptibility to oils and petrochemicals. Levels of oils or petrochemicals in the sediment which cause deleterious effects to the biota should not be allowed. Surface waters shall be virtually free from floating non–petroleum oils of vegetable or animal origin as well as petroleum derived oils.

APPENDIX B2.12- IV

HISTORICAL WATER QUALITY DATA

Table 1 Surface Water Sampling Results May 1997 (Round 1)

Analysis		Detection Limits	Water Supply Infrastructure						Watercourse Sampling Points						
			Borehole1	Reservoirs 2		Distribution System 3			4	5	6	7	8	9	0
Inorganics		**mg/L**	**1-1A**	**2.1-1A**	**2.2-1A**	**3.1-1A**	**3.2-1A**	**3.3-1A**	**4-1A**	**5-1A**	**6-1A**	**7-1A**	**8-1A**	**9-1A**	**10-1A**
Na^+	mg/L	0.03	-	-	-	-	-	-	58.6	44.1	42.7	41.8	39	41.7	37.7
K^+	mg/L	0.02	-	-	-	-	-	-	31.6	32.6	43.6	14.9	24.9	25.6	15.2
Ca^{2+}	mg/L	0.01	-	-	-	-	-	-	25	15.7	30.8	4.8	3.6	0.6	2.1
Mg^{2+}	mg/L	0.01	-	-	-	-	-	-	11	11.3	10.9	10.6	11.2	9.7	8.5
NH_4^+	mg/L	0.01	-	-	-	-	-	-	57	57	57	57	77	77	77
NO_2^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	-	-	-	-	-	-	225	66	79	50	67	60	61
SO_4^{2-}	mg/L	0.03	-	-	-	-	-	-	72.4	683.1	29.6	41.2	680	23	13.2
PO_4^{2-}	mg/L	0.05	-	-	-	-	-	-	96.7	77.4	85.6	78.7	77.6	80.7	89.7
HCO_3^-	mg/L	0.01	-	-	-	-	-	-	n/d	n/d	n/d	n/d	5.7	9.5	3.6
CO_3^{2-}	mg/L	0.01	-	-	-	-	-	-	266.2	275.7	193.8	315.2	310.3	294.7	211
SiO_2	mg/L	0.05	-	-	-	-	-	-	2.56	1.08	1.12	0.92	0.28	0.24	0.6
Metals		**µg/L**	**1-1B**	**2.1-1B**	**2.2-1B**	**3.1-1B**	**3.2-1B**	**3.3-1B**	**4-1B**	**5-1B**	**6-1B**	**7-1B**	**8-1B**	**9-1B**	**10-1B**
Mn	µg/L	0.09	-	-	-	-	-	-	300	200	225	250	250	250	250
Fe (III)	µg/L	100.00	-	-	-	-	-	-	17	n/d	n/d	n/d	6	12	15
Fe Total	µg/L	9.00	-	-	-	-	-	-	125	75	250	375	475	925	900
Al	µg/L	1.00	-	-	-	-	-	-	n/d	n/d	n/d	n/d	n/d	n/d	n/d
As	µg/L	8.00	-	-	-	-	-	-	88	45	63	43	61	63	76
Cd	µg/L	0.20	-	-	-	-	-	-	n/d	n/d	n/d	n/d	n/d	n/d	n/d
Ni	µg/L	0.60	-	-	-	-	-	-	100	75	200	225	225	250	200
Pb	µg/L	8.00	-	-	-	-	-	-	125	150	75	125	125	250	200
Cu	µg/L	0.60	-	-	-	-	-	-	n/d	n/d	n/d	n/d	n/d	n/d	n/d
Cr	µg/L	0.50	-	-	-	-	-	-	11.5	9.5	13	8	13	8	13
Hg	µg/L	5.00	-	-	-	-	-	-	27.5	18.5	20.5	12.5	8.5	13	13
Zn	µg/L	0.40	-	-	-	-	-	-	n/d	n/d	n/d	n/d	n/d	n/d	n/d
Co	µg/L	9.00	-	-	-	-	-	-	21.5	18	20	14.5	15	11.5	23

Table 1 Surface Water Sampling Results May 1997 (Round 1) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			11	12	13	14	15	16	17	18	19	20	21	22	23
Inorganics		**mg/L**	**11-1A**	**12-1A**	**13-1A**	**14-1A**	**15-1A**	**16-1A**	**17-1A**	**18-1A**	**19-1A**	**20-1A**	**21-1A**	**22-1A**	**23-1A**
Na^+	mg/L	0.03	36.6	37.8	38	38.3	37.7	35.9	-	-	-	-	-	-	-
K^+	mg/L	0.02	19	21.6	21.3	25.1	19.9	18.2	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	1.3	13.7	2.3	7.2	5	1.8	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	11.1	10.8	11.3	17.3	13.6	13.6	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	77	71	71	77	84	77	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	51	52	51	85	73	46	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	16.5	29.6	6.6	6.6	31.3	32.9	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	73.8	80.6	109.1	84.5	83.7	71.7	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	2.9	1.9	n/d	n/d	n/d	n/d	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	209.1	214.9	254.8	266.2	275.7	275.3	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	0.24	0.7	2.6	2.6	1.12	0.92	-	-	-	-	-	-	-
Metals		**µg/L**	**11-1B**	**12-1B**	**13-1B**	**14-1B**	**15-1B**	**16-1B**	**17-5A**	**18-1B**	**19-1B**	**20-1B**	**21-1B**	**22-1B**	**23-1B**
Mn	µg/L	0.09	225	225	375	225	300	375	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	13	31	9	4	19	30	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	950	1100	1150	1325	1400	1525	-	-	-	-	-	-	-
Al	µg/L	1.00	n/d	n/d	n/d	n/d	n/d	n/d	-	-	-	-	-	-	-
As	µg/L	8.00	48	86	75	61	92	98	-	-	-	-	-	-	-
Cd	µg/L	0.20	n/d	n/d	n/d	n/d	n/d	n/d	-	-	-	-	-	-	-
Ni	µg/L	0.60	325	350	375	325	400	375	-	-	-	-	-	-	-
Pb	µg/L	8.00	325	350	375	325	475	550	-	-	-	-	-	-	-
Cu	µg/L	0.60	n/d	n/d	n/d	n/d	n/d	n/d	-	-	-	-	-	-	-
Cr	µg/L	0.50	19.5	4.5	20	21	6.5	16.5	-	-	-	-	-	-	-
Hg	µg/L	5.00	14	19	22.5	28	27	24	-	-	-	-	-	-	-
Zn	µg/L	0.40	n/d	n/d	n/d	n/d	n/d	n/d	-	-	-	-	-	-	-
Co	µg/L	9.00	11.5	23	19.5	9.5	20	14.5	-	-	-	-	-	-	-

Table 1 Surface Water Sampling Results May 1997 (Round 1) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			24	25	26	27	28	29	30	31	32	33	34	35	36
Inorganics		**mg/L**	**24-1A**	**25-1A**	**26-1A**	**27-1A**	**28-1A**	**29-1A**	**30-1A**	**31-1A**	**32-1A**	**33-1A**	**34-1A**	**35-1A**	**36-1A**
Na^+	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**24-1B**	**25-1B**	**26-1B**	**27-1B**	**28-1B**	**29-1B**	**30-1B**	**31-1B**	**32-1B**	**33-1B**	**34-1B**	**35-1B**	**36-1B**
Mn	µg/L	0.09	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	-	-	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 1 Surface Water Sampling Results May 1997 (Round 1) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			37	38	39	40	41	42	43	44	45	46	47	48	49
Inorganics		**mg/L**	**37-1A**	**38-1A**	**39-1A**	**40-1A**	**41-1A**	**42-1A**	**43-1A**	**44-1A**	**45-1A**	**46-1A**	**47-1A**	**48-1A**	**49-1A**
Na^+	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**37-1B**	**38-1B**	**39-1B**	**40-1B**	**41-1B**	**42-1B**	**43-1B**	**44-1B**	**45-1B**	**46-1B**	**47-1B**	**48-1B**	**49-1B**
Mn	µg/L	0.09	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	-	-	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 1 Surface Water Sampling Results May 1997 (Round 1) (continued)

Analysis		Detection Limits	Quality Assurance Samples										
			50	51	52	53	54	55	56	57	58	59	60
Inorganics		**mg/L**	**50-1A**	**51-1A**	**52-1A**	**53-1A**	**54-1A**	**55-1A**	**56-1A**	**57-1A**	**58-1A**	**59-1A**	**60-1A**
Na^+	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**50-1B**	**51-1B**	**52-1B**	**53-1B**	**54-1B**	**55-1B**	**56-1B**	**57-1B**	**58-1B**	**59-1B**	**60-1B**
Mn	µg/L	0.09	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	-	-	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	-	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-

Table 1 Surface Water Sampling Results May 1997 (Round 1) (continued)

Analysis		Detection Limits	Fungurume Wells										Tenke Wells		
			101	102	103	104	105	106	107	108	109	110	111	112	113
Inorganics		**mg/L**	**101-1A**	**102-1A**	**103-1A**	**104-1A**	**105-1A**	**106-1A**	**107-1A**	**108-1A**	**109-1A**	**110-1A**	**111-1A**	**112-1A**	**113-1A**
Na^+	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**101-1B**	**102-1B**	**103-1B**	**104-1B**	**105-1B**	**106-1B**	**107-1B**	**108-1B**	**109-1B**	**110-1B**	**111-1B**	**112-1B**	**113-1B**
Mn	µg/L	0.09	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	-	-	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2 Surface Water Sampling Results June 1997 (Round 2)

Analysis		Detection Limits	Water Supply Infrastructure						Watercourse Sampling Points						
			Borehole 1	Reservoirs 2		Distribution System 3			4	5	6	7	8	9	10
Inorganics		**mg/L**	**1-5A**	**2.1-2A**	**2.2-2A**	**3.1-2A**	**3.2-2A**	**3.3-2A**	**4-2A**	**5-2A**	**6-2A**	**7-2A**	**8-2A**	**9-2A**	**10-2A**
Na^+	mg/L	0.03	-	-	-	-	-	-	377	12	19	3	3.9	3.7	16
K^+	mg/L	0.02	-	-	-	-	-	-	9.7	3.2	3.4	3.4	3.7	3.7	3.4
Ca^{2+}	mg/L	0.01	-	-	-	-	-	-	116	63	62	72	74	59	63
Mg^{2+}	mg/L	0.01	-	-	-	-	-	-	87	56	38	59	58	53	43
NH_4^+	mg/L	0.01	-	-	-	-	-	-	0.57	1.08	0.51	0.91	0.45	0.99	0.68
NO_2^-	mg/L	0.01	-	-	-	-	-	-	0.1	<	<0.01	<0.01	0.02	0.01	0.02
NO_3^-	mg/L	0.01	-	-	-	-	-	-	15.4	46.97	21.7	15.5	17.03	24.79	37.18
Cl^-	mg/L	10.00	-	-	-	-	-	-	39	i/s	48	i/s	48	39	45
SO_4^{2-}	mg/L	0.03	-	-	-	-	-	-	349	73	53	29	105	56	61
PO_4^{2-}	mg/L	0.05	-	-	-	-	-	-	1.05	0.8	0.6	0.8	0.7	0.6	0.7
HCO_3^-	mg/L	0.01	-	-	-	-	-	-	320	314	296	364	326	300	280
CO_3^{2-}	mg/L	0.01	-	-	-	-	-	-	<	<	<	<	<	<	<
SiO_2	mg/L	0.05	-	-	-	-	-	-	34	24	29	25	25	25	28
Metals		**µg/L**	**1-2B**	**2.1-2B**	**2.2-2B**	**3.1-2B**	**3.2-2B**	**3.3-2B**	**4-2B**	**5-2B**	**6-2B**	**7-2B**	**8-2B**	**9-2B**	**10-2B**
Mn	µg/L	0.09	-	-	-	-	-	-	390	5	79.1	208	2.956	5.87	9.37
Fe (III)	µg/L	100.00	-	-	-	-	-	-	<100	<	<	<	<	<	<
Fe Total	µg/L	9.00	-	-	-	-	-	-	266	<9	<	262.9	<	<	<
Al	µg/L	1.00	-	-	-	-	-	-	<1.00	<1	<	<	<	<	<
As	µg/L	8.00	-	-	-	-	-	-	<8.00	9	<	8.08	<	8.02	9.71
Cd	µg/L	0.20	-	-	-	-	-	-	<0.20	<	<	<	<	<	<
Ni	µg/L	0.60	-	-	-	-	-	-	<0.60	<	<	<	<	<	<
Pb	µg/L	8.00	-	-	-	-	-	-	<	9	<	<	<	<	<
Cu	µg/L	0.60	-	-	-	-	-	-	<0.60	<	<	<	<	<	<
Cr	µg/L	0.50	-	-	-	-	-	-	<	<	<	<	<	<	<
Hg	µg/L	5.00	-	-	-	-	-	-	<	<	<	<	<	<	<
Zn	µg/L	0.40	-	-	-	-	-	-	9.47	<	11.99	21.91	13.87	13.58	10.36
Co	µg/L	9.00	-	-	-	-	-	-	18.5	10	20.73	14.84	13.09	15.12	15.12

Table 2 Surface Water Sampling Results June 1997 (Round 2) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			11	12	13	14	15	16	17	18	19	20	21	22	23
Inorganics		**mg/L**	**11-2A**	**12-2A**	**13-2A**	**14-2A**	**15-2A**	**16-2A**	**17-2A**	**18-2A**	**19-2A**	**20-2A**	**21-2A**	**22-2A**	**23-2A**
Na^+	mg/L	0.03	2.5	16	27	5.2	4.8	9.4	3.9	8.9	4.1	21	4.6	38	3.8
K^+	mg/L	0.02	2.3	3.4	4.4	3.5	3.5	3.4	3.6	1.5	3.5	5.3	3.9	3.2	3.2
Ca^{2+}	mg/L	0.01	46	64	92	60	63	64	87	18	54	73	74	97	55
Mg^{2+}	mg/L	0.01	47	43	47	52	55	56	69	20	46	47	69	38	50
NH_4^+	mg/L	0.01	0.65	0.43	0.74	0.77	0.99	0.71	0.51	0.91	0.51	0.6	0.45	0.65	0.51
NO_2^-	mg/L	0.01	0.01	0.02	0.01	<	0.01	0.02	0.01	0.02	0.03	0.02	0.02	0.03	0.02
NO_3^-	mg/L	0.01	29.44	34.08	30.99	21.7	27.89	34.09	21.69	23.23	34.07	24.78	5.56	92.97	6.98
Cl^-	mg/L	10.00	39	45	42	36	39	39	36	42	45	45	48	42	42
SO_4^{2-}	mg/L	0.03	30	63	0.5	52	61	68	110	0.4	15	25	115	22	6
PO_4^{2-}	mg/L	0.05	0.6	0.6	0.9	0.7	0.7	0.8	0.9	0.4	0.7	0.78	0.7	0.8	0.8
HCO_3^-	mg/L	0.01	260	282	412	300	298	308	378	129	278	340	340	382	300
CO_3^{2-}	mg/L	0.01	<	<	<	<	<	<	<	<	<	<	<	<	<
SiO_2	mg/L	0.05	22	28	38	25	25	24	24	22	29	26	26	37	23
Metals		**µg/L**	**11-2B**	**12-2B**	**13-2B**	**14-2B**	**15-2B**	**16-2B**	**17-5A**	**18-2B**	**19-2B**	**20-2B**	**21-2B**	**22-2B**	**23-2B**
Mn	µg/L	0.09	9	13	123	14	13	<	6	600	1.02	233.9	11.62	50	<
Fe (III)	µg/L	100.00	<	<	<	<	<	<	<	1670	<	<	<	<	<
Fe Total	µg/L	9.00	<	<	<	<	<	<	<	2328	<	<	<	<	<
Al	µg/L	1.00	<	<	<	<	<	<	<	<	<	<	<	<	<
As	µg/L	8.00	8	9	9	9	10	<	9	<	<	9.75	8.64	11	7
Cd	µg/L	0.20	<	<	<	<	<	<	<	<	<	<	<	<	<
Ni	µg/L	0.60	<	<	<	<	<	<	<	<	<	<	<	<	<
Pb	µg/L	8.00	<	<	8	8	<	10	10.6	<	<	<	7.5	<	<
Cu	µg/L	0.60	<	<	<	<	<	<	<	<	<	<	<	<	61
Cr	µg/L	0.50	<	<	<	<	<	<	<	<	<	<	<	<	<
Hg	µg/L	5.00	<	<	<	<	<	<	<	<	<	<	<	<	<
Zn	µg/L	0.40	14	10	15	17	16	<	12.21	12.2	12.01	14.19	11	11	32
Co	µg/L	9.00	16	12	18	15	11	<	10.47	16	9.6	8.79	10.97	15	15

Table 2 Surface Water Sampling Results June 1997 (Round 2) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			24	25	26	27	28	29	30	31	32	33	34	35	36
Inorganics		**mg/L**	**24-2A**	**25-2A**	**26-2A**	**27-2A**	**28-2A**	**29-2A**	**30-2A**	**31-2A**	**32-2A**	**33-2A**	**34-2A**	**35-2A**	**36-2A**
Na^+	mg/L	0.03	-	3.7	13	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	-	2	3.6	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	-	24	67	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	-	20	59	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	-	0.74	1.25	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	0.01	0.02	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	57.34	10.83	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	-	45	39	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	-	0.2	82	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	-	0.3	0.7	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	-	129	308	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	-	<	<	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	-	16	24	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**24-2B**	**25-2B**	**26-2B**	**27-2B**	**28-2B**	**29-2B**	**30-2B**	**31-2B**	**32-2B**	**33-2B**	**34-2B**	**35-2B**	**36-2B**
Mn	µg/L	0.09	-	29.79	30	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	-	<	<	-	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	-	<	<	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	-	<	<	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	-	10	<	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	-	<	<	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	-	<	<	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	-	<	<	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	-	<	<	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	-	<	<	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	-	<	<	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	-	13.4	15	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	-	17.65	17	-	-	-	-	-	-	-	-	-	-

Table 2 Surface Water Sampling Results June 1997 (Round 2) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			37	38	39	40	41	42	43	44	45	46	47	48	49
Inorganics		**mg/L**	**37-2A**	**38-2A**	**39-2A**	**40-2A**	**41-2A**	**42-2A**	**43-2A**	**44-2A**	**45-2A**	**46-2A**	**47-2A**	**48-2A**	**49-2A**
Na^+	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**37-2B**	**38-2B**	**39-2B**	**40-2B**	**41-2B**	**42-2B**	**43-2B**	**44-2B**	**45-2B**	**46-2B**	**47-2B**	**48-2B**	**49-2B**
Mn	µg/L	0.09	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	-	-	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2 Surface Water Sampling Results June 1997 (Round 2) (continued)

Analysis		Detection Limits	Quality Assurance Samples										
			50	51	52	53	54	55	56	57	58	59	60
Inorganics		**mg/L**	**50-2A**	**51-2A**	**52-2A**	**53-2A**	**54-2A**	**55-2A**	**56-2A**	**57-2A**	**58-2A**	**59-2A**	**60-2A**
Na^+	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**50-2B**	**51-2B**	**52-2B**	**53-2B**	**54-2B**	**55-2B**	**56-2B**	**57-2B**	**58-2B**	**59-2B**	**60-2B**
Mn	µg/L	0.09	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	-	-	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	-	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-

Table 2 Surface Water Sampling Results June 1997 (Round 2) (continued)

Analysis		Detection Limits	Fungurume Wells										Tenke Wells		
			101	102	103	104	105	106	107	108	109	110	111	112	113
Inorganics		**mg/L**	**101-1A**	**102-1A**	**103-1A**	**104-1A**	**105-1A**	**106-1A**	**107-1A**	**108-1A**	**109-1A**	**110-1A**	**111-1A**	**112-1A**	**113-1A**
Na^+	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**101-1B**	**102-1B**	**103-1B**	**104-1B**	**105-1B**	**106-1B**	**107-1B**	**108-1B**	**109-1B**	**110-1B**	**111-1B**	**112-1B**	**113-1B**
Mn	µg/L	0.09	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	-	-	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3 Surface Water Sampling Results August 1997 (Round 3)

Analysis		Detection Limits	Water Supply Infrastructure						Watercourse Sampling Points						
			Borehole 1	Reservoirs 2		Distribution System 3			4	5	6	7	8	9	10
Inorganics		**mg/L**	**1-3A**	**2.1-3A**	**2.2-3A**	**3.1-3A**	**3.2-3A**	**3.3-3A**	**4-3A**	**5-3A**	**6-3A**	**7-3A**	**8-3A**	**9-3A**	**10-3A**
Na^+	mg/L	0.03	9	-	-	<10.0	<10.0	-	250	14.2	42.9	<10.0	<10.0	<10.0	35.3
K^+	mg/L	0.02	<0.02	-	-	<0.02	<0.02	-	1	<0.02	<.0.02	<0.02	<0.02	<0.02	<0.02
Ca^{2+}	mg/L	0.01	74.1	-	-	74.4	22.8	-	124	65.5	69.7	87	77.7	79.2	73.7
Mg^{2+}	mg/L	0.01	67.3	-	-	68.4	0.38	-	89.2	57.8	40.6	61.4	58.5	53.5	48.8
NH_4^+	mg/L	0.01	0.86	-	-	1.44	2.58	-	2.44	1.44	2.44	3.86	2.26	2	1.62
NO_2^-	mg/L	0.01	2.58	-	-	0.24	0.12	-	0.12	0.16	0.16	0.08	0.04	0.04	0.12
NO_3^-	mg/L	0.01	<10	-	-	<10	<10	-	<10	<10	<10	207	294	102	55
Cl^-	mg/L	10.00	8.4	-	-	7.8	8.4	-	7.8	8.4	9	8.4	8.4	8.4	8.4
SO_4^{2-}	mg/L	0.03	69.3	-	-	79.5	10.3	-	449	98.3	90.4	60	139	84.9	109
PO_4^{2-}	mg/L	0.05	<0.05	-	-	<0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
HCO_3^-	mg/L	0.01	370	-	-	381	6	-	357	311	286	340	312	291	307
CO_3^{2-}	mg/L	0.01	24	-	-	28	<	-	21	24	34	26	27	20	23
SiO_2	mg/L	0.05	10.7	-	-	10.6	<0.05	-	15.9	10.4	14	10.3	11.2	9.93	13.7
Metals		**µg/L**	**1-3B**	**2.1-3B**	**2.2-3B**	**3.1-3B**	**3.2-3B**	**3.3-3B**	**4-3B**	**5-3B**	**6-3B**	**7-3B**	**8-3B**	**9-3B**	**10-3B**
Mn	µg/L	0.09	18.95	-	-	12.58	35.66	-	756	13.45	40.85	36.47	0.29	27.02	11.06
Fe (III)	µg/L	100.00	190	-	-	870	<100	-	600	<	<	<	<	<	<
Fe Total	µg/L	9.00	161.6	-	-	1071	55.5	-	564	<9.00	<9.00	92.7	<9.00	31.99	<9.00
Al	µg/L	1.00	375.3	-	-	314.3	1971	-	1577	77.4	<1	1761	44.89	1042	446
As	µg/L	8.00	8.67	-	-	11.9	4.58	-	9	10.5	8	8.8	8	10.6	8
Cd	µg/L	0.20	<0.2	-	-	<0.2	<0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ni	µg/L	0.60	<0.6	-	-	<0.6	<0.6	-	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Pb	µg/L	8.00	7.09	-	-	17.22	2.89	-	<8.00	<8.00	<8.00	<8.00	<8.00	<8.00	<8.00
Cu	µg/L	0.60	63.5	-	-	13.11	<0.60	-	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Cr	µg/L	0.50	<0.5	-	-	<0.5	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Hg	µg/L	5.00	<5.00	-	-	<5.00	<5.00	-	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Zn	µg/L	0.40	691	-	-	4972	1881	-	1416	47.67	<0.4	3630	64.4	1091	2095
Co	µg/L	9.00	<9.00	-	-	<9.00	<9.00	-	<9.00	<9.00	<9.00	<9.00	<9.00	<9.00	<9.00

Table 3 Surface Water Sampling Results August 1997 (Round 3) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			11	12	13	14	15	16	17	18	19	20	21	22	23
Inorganics		**mg/L**	**11-3A**	**12-3A**	**13-3A**	**14-3A**	**15-3A**	**16-3A**	**17-3A**	**18-3A**	**19-3A**	**20-3A**	**21-3A**	**22-3A**	**23-3A**
Na^+	mg/L	0.03	<10.0	33.6	101	11.4	11	12.9	10	-	11.9	-	10.7	92.4	<10.0
K^+	mg/L	0.02	<0.02	<0.02	105	<0.02	<0.02	<0.02	<0.02	-	<0.02	-	<0.02	<0.02	<0.02
Ca^{2+}	mg/L	0.01	65.3	70.3	104	64.1	68	76.4	92.4	-	56.4	-	78.5	126	58.5
Mg^{2+}	mg/L	0.01	47.6	48.8	103	54.7	57.5	58.6	71.4	-	47.1	-	70.4	39.9	51.2
NH_4^+	mg/L	0.01	1.5	1.14	0.9	0.86	1.58	2.58	1.26	-	1.18	-	1.22	1.24	1.8
NO_2^-	mg/L	0.01	0.16	0.2	0.2	0.2	0.24	0.2	0.24	-	0.2	-	0.24	0.24	0.2
NO_3^-	mg/L	0.01	64	61	89	33	95	145	117	-	52	-	58	123	49
Cl^-	mg/L	10.00	7.8	8.4	8.4	8.4	7.8	7.8	8.4	-	9	-	8.4	8.4	8.4
SO_4^{2-}	mg/L	0.03	55.8	101	115	73.7	89.9	109	158	-	43.7	-	162	46.4	10.3
PO_4^{2-}	mg/L	0.05	<.0.05	<0.05	166	<0.05	<0.05	<0.05	<0.05	-	<0.05	-	<0.05	<0.05	<0.05
HCO_3^-	mg/L	0.01	260	302	415	298	315	316	370	-	284	-	322	388	298
CO_3^{2-}	mg/L	0.01	23	31	9	16	3	8	<	-	<	-	8	7	22
SiO_2	mg/L	0.05	9.57	13.7	102	11.2	11	10.9	11	-	13.4	-	12.1	20.5	10.4
Metals		**µg/L**	**11-3B**	**12-3B**	**13-3B**	**14-3B**	**15-3B**	**16-3B**	**17-3B**	**18-3B**	**19-3B**	**20-3B**	**21-3B**	**22-3B**	**23-3B**
Mn	µg/L	0.09	32.91	6.94	130	6.23	10.8	21.2	3.31	-	8.39	-	15.4	33.6	<0.09
Fe (III)	µg/L	100.00	65	<	140	<	<	<	<	-	140	-	<	<	<
Fe Total	µg/L	9.00	40.34	<9.00	144	<9.00	<9.00	33	<9.00	-	373	-	13.1	16.9	<9.00
Al	µg/L	1.00	1571	71.2	2354	137	290	955	127	-	1875	-	77.6	450	274
As	µg/L	8.00	10.7	12.6	11.5	10	7.46	7.62	8.54	-	12.6	-	11	12.6	8.41
Cd	µg/L	0.20	0.64	<0.2	34.2	<0.2	<0.2	<0.2	<0.2	-	<0.2	-	<0.2	<0.2	<0.2
Ni	µg/L	0.60	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	-	<0.6	-	<0.6	<0.6	<0.6
Pb	µg/L	8.00	<8.00	<8.00	<8.00	<8.00	<8.00	<8.00	<8.00	-	<8.00	-	<8.00	<8.00	<8.00
Cu	µg/L	0.60	1.03	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	-	18.9	-	<0.6	<0.6	42.9
Cr	µg/L	0.50	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	66.4	-	<0.5	<0.5	<0.5
Hg	µg/L	5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	-	<5.00	-	<5.00	<5.00	<5.00
Zn	µg/L	0.40	2769	72.7	1378	533	922	2638	714	-	7441	-	73.3	398	510
Co	µg/L	9.00	<9.00	<9.00	<9.00	<9.00	<9.00	<9.00	<9.00	-	<9.00	-	<9.00	<9.00	<9.00

Table 3 Surface Water Sampling Results August 1997 (Round 3) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			24	25	26	27	28	29	30	31	32	33	34	35	36
Inorganics		**mg/L**	**24-3A**	**25-3A**	**26-3A**	**27-3A**	**28-3A**	**29-3A**	**30-3A**	**31-3A**	**32-3A**	**33-3A**	**34-3A**	**35-3A**	**36-3A**
Na^+	mg/L	0.03	-	-	22.2	-	-	-	-	-	-	-	-	-	13.5
K^+	mg/L	0.02	-	-	<0.02	-	-	-	-	-	-	-	-	-	<0.02
Ca^{2+}	mg/L	0.01	-	-	69	-	-	-	-	-	-	-	-	-	87.9
Mg^{2+}	mg/L	0.01	-	-	60.6	-	-	-	-	-	-	-	-	-	74.6
NH_4^+	mg/L	0.01	-	-	0.9	-	-	-	-	-	-	-	-	-	1.44
NO_2^-	mg/L	0.01	-	-	0.28	-	-	-	-	-	-	-	-	-	0.28
NO_3^-	mg/L	0.01	-	-	61	-	-	-	-	-	-	-	-	-	722
Cl^-	mg/L	10.00	-	-	8.4	-	-	-	-	-	-	-	-	-	8.4
SO_4^{2-}	mg/L	0.03	-	-	113	-	-	-	-	-	-	-	-	-	36.9
PO_4^{2-}	mg/L	0.05	-	-	<0.05	-	-	-	-	-	-	-	-	-	<0.05
HCO_3^-	mg/L	0.01	-	-	319	-	-	-	-	-	-	-	-	-	400
CO_3^{2-}	mg/L	0.01	-	-	36	-	-	-	-	-	-	-	-	-	21
SiO_2	mg/L	0.05	-	-	11	-	-	-	-	-	-	-	-	-	14.6
Metals		**µg/L**	**24-3B**	**25-3B**	**26-3B**	**27-3B**	**28-3B**	**29-3B**	**30-3B**	**31-3B**	**32-3B**	**33-3B**	**34-3B**	**35-3B**	**36-3B**
Mn	µg/L	0.09	-	-	20.7	-	-	-	-	-	-	-	-	-	14.1
Fe (III)	µg/L	100.00	-	-	<	-	-	-	-	-	-	-	-	-	<
Fe Total	µg/L	9.00	-	-	<9.00	-	-	-	-	-	-	-	-	-	8.96
Al	µg/L	1.00	-	-	50.8	-	-	-	-	-	-	-	-	-	660
As	µg/L	8.00	-	-	11	-	-	-	-	-	-	-	-	-	11
Cd	µg/L	0.20	-	-	<0.2	-	-	-	-	-	-	-	-	-	<0.2
Ni	µg/L	0.60	-	-	<0.6	-	-	-	-	-	-	-	-	-	<0.6
Pb	µg/L	8.00	-	-	<8.00	-	-	-	-	-	-	-	-	-	<8.00
Cu	µg/L	0.60	-	-	<0.6	-	-	-	-	-	-	-	-	-	<0.6
Cr	µg/L	0.50	-	-	<0.5	-	-	-	-	-	-	-	-	-	<0.5
Hg	µg/L	5.00	-	-	<5.00	-	-	-	-	-	-	-	-	-	<5.00
Zn	µg/L	0.40	-	-	30	-	-	-	-	-	-	-	-	-	984
Co	µg/L	9.00	-	-	<9.00	-	-	-	-	-	-	-	-	-	<9.00

Table 3 Surface Water Sampling Results August 1997 (Round 3) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			37	38	39	40	41	42	43	44	45	46	47	48	49
Inorganics		**mg/L**	**37-3A**	**38-3A**	**39-3A**	**40-3A**	**41-3A**	**42-3A**	**43-3A**	**44-3A**	**45-3A**	**46-3A**	**47-3A**	**48-3A**	**49-3A**
Na^+	mg/L	0.03	<10.0	-	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	<0.02	-	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	79.6	-	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	67.1	-	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	1.9	-	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	0.2	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	74	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	7.8	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	124	-	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	<0.05	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	362	-	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	18	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	10.5	-	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**37-3B**	**38-3B**	**39-3B**	**40-3B**	**41-3B**	**42-3B**	**43-3B**	**44-3B**	**45-3B**	**46-3B**	**47-3B**	**48-3B**	**49-3B**
Mn	µg/L	0.09	14.9	-	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	<	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	11.3	-	-	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	<1	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	6.43	-	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	<0.2	-	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	<0.6	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	<8.00	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	<0.6	-	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	<0.5	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	<5.00	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	<0.40	-	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	<9.00	-	-	-	-	-	-	-	-	-	-	-	-

Table 3 Surface Water Sampling Results August 1997 (Round 3) (continued)

Analysis		Detection Limits	Quality Assurance Samples										
			50	51	52	53	54	55	56	57	58	59	60
Inorganics		**mg/L**	**50-3A**	**51-3A**	**52-3A**	**53-3A**	**54-3A**	**55-3A**	**56-3A**	**57-3A**	**58-3A**	**59-3A**	**60-3A**
Na^+	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**50-3B**	**51-3B**	**52-3B**	**53-3B**	**54-3B**	**55-3B**	**56-3B**	**57-3B**	**58-3B**	**59-3B**	**60-3B**
Mn	µg/L	0.09	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	-	-	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	-	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-

Table 3 Surface Water Sampling Results August 1997 (Round 3) (continued)

Analysis		Detection Limits	Fungurume Wells									Tenke Wells			
			101	102	103	104	105	106	107	108	109	110	111	112	113
Inorganics		**mg/L**	**101-3A**	**102-3A**	**103-3A**	**104-3A**	**105-3A**	**106-3A**	**107-3A**	**108-3A**	**109-3A**	**110-3A**	**111-3A**	**112-3A**	**113-3A**
Na^+	mg/L	0.03	11.6	18.8	13.9	11.71	18.6	16.6	32.1	65.2	34.9	-	-	-	-
K^+	mg/L	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-	-	-	-
Ca^{2+}	mg/L	0.01	11.4	137	77.7	48.7	56.4	29.6	24.6	12	34.6	-	-	-	-
Mg^{2+}	mg/L	0.01	11.2	55.6	46.6	36.8	33.6	15.8	4.89	22.7	38.1	-	-	-	-
NH_4^+	mg/L	0.01	2.8	1.8	1.24	1.86	0.82	0.86	0.64	1.74	1.4	-	-	-	-
NO_2^-	mg/L	0.01	0.28	0.28	0.28	0.32	0.8	2.92	0.56	0.94	0.4	-	-	-	-
NO_3^-	mg/L	0.01	71	64	133	196	154	152	98	172	36	-	-	-	-
Cl^-	mg/L	10.00		7.8	8.4	9	8.4	8.4	8.4	7.8	7.8	-	-	-	-
SO_4^{2-}	mg/L	0.03	11	129	87.7	63.1	64.7	25.6	18	23.7	64.9	-	-	-	-
PO_4^{2-}	mg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-
HCO_3^-	mg/L	0.01	60	300	260	214	150	50	8	76	191	-	-	-	-
CO_3^{2-}	mg/L	0.01	<	2	4	5	3	<	<	26	<	-	-	-	-
SiO_2	mg/L	0.05	10.9	11.1	10.6	9.85	15.8	12.8	12.5	26.3	24.8	-	-	-	-
Metals		**µg/L**	**101-3B**	**102-3B**	**103-3B**	**104-3B**	**105-3B**	**106-3B**	**107-3B**	**108-3B**	**109-3B**	**110-3B**	**111-3B**	**112-3B**	**113-3B**
Mn	µg/L	0.09	7.84	106	80.2	60	50.6	170	128	247	146	-	-	-	-
Fe (III)	µg/L	100.00	<	<	<	<	<	420	<	<	<	-	-	-	-
Fe Total	µg/L	9.00	11.3	19.7	46.5	<9.00	7.23	1664	106	<9.00	<9.00	-	-	-	-
Al	µg/L	1.00	561	657	1930	5.34	907	2714	2099	289	182	-	-	-	-
As	µg/L	8.00	8	7.88	12	10.2	7.25	6.44	7.66	8.68	9.21	-	-	-	-
Cd	µg/L	0.20	1.82	25.3	1.76	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	-	-	-	-
Ni	µg/L	0.60	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	21	33.8	<0.6	-	-	-	-
Pb	µg/L	8.00	<8.00	<8.00	<8.00	<8.00	<8.00	<8.00	<8.00	<8.00	<8.00	-	-	-	-
Cu	µg/L	0.60	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	7.65	<0.6	<0.6	-	-	-	-
Cr	µg/L	0.50	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-	-	-	-
Hg	µg/L	5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	-	-	-	-
Zn	µg/L	0.40	1004	2023	1342	117	1235	2873	3206	546	361	-	-	-	-
Co	µg/L	9.00	<9.00	<9.00	<9.00	<9.00	<9.00	<9.00	79.3	53.1	<9.00	-	-	-	-

Table 4 Surface Water Sampling Results September 1997 (Round 4)

Analysis		Detection Limits	Water Supply Infrastructure						Watercourse Sampling Points						
			Borehole 1	Reservoirs 2		Distribution System 3			4	5	6	7	8	9	10
Inorganics		**mg/L**	**1-3A**	**2.1-3A**	**2.2-3A**	**3.1-3A**	**3.2-3A**	**3.3-3A**	**4-3A**	**5-3A**	**6-3A**	**7-3A**	**8-3A**	**9-3A**	**10-3A**
Na^+	mg/L	0.03	9	-	-	<10.0	<10.0	-	250	14.2	42.9	<10.0	<10.0	<10.0	35.3
K^+	mg/L	0.02	<0.02	-	-	<0.02	<0.02	-	1	<0.02	<.0.02	<0.02	<0.02	<0.02	<0.02
Ca^{2+}	mg/L	0.01	74.1	-	-	74.4	22.8	-	124	65.5	69.7	87	77.7	79.2	73.7
Mg^{2+}	mg/L	0.01	67.3	-	-	68.4	0.38	-	89.2	57.8	40.6	61.4	58.5	53.5	48.8
NH_4^+	mg/L	0.01	0.86	-	-	1.44	2.58	-	2.44	1.44	2.44	3.86	2.26	2	1.62
NO_2^-	mg/L	0.01	2.58	-	-	0.24	0.12	-	0.12	0.16	0.16	0.08	0.04	0.04	0.12
NO_3^-	mg/L	0.01	<10	-	-	<10	<10	-	<10	<10	<10	207	294	102	55
Cl^-	mg/L	10.00	8.4	-	-	7.8	8.4	-	7.8	8.4	9	8.4	8.4	8.4	8.4
SO_4^{2-}	mg/L	0.03	69.3	-	-	79.5	10.3	-	449	98.3	90.4	60	139	84.9	109
PO_4^{2-}	mg/L	0.05	<0.05	-	-	<0.05	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
HCO_3^-	mg/L	0.01	370	-	-	381	6	-	357	311	286	340	312	291	307
CO_3^{2-}	mg/L	0.01	24	-	-	28	<	-	21	24	34	26	27	20	23
SiO_2	mg/L	0.05	10.7	-	-	10.6	<0.05	-	15.9	10.4	14	10.3	11.2	9.93	13.7
Metals		**µg/L**	**1-3B**	**2.1-3B**	**2.2-3B**	**3.1-3B**	**3.2-3B**	**3.3-3B**	**4-3B**	**5-3B**	**6-3B**	**7-3B**	**8-3B**	**9-3B**	**10-3B**
Mn	µg/L	0.09	18.95	-	-	12.58	35.66	-	756	13.45	40.85	36.47	0.29	27.02	11.06
Fe (III)	µg/L	100.00	190	-	-	870	<100	-	600	<	<	<	<	<	<
Fe Total	µg/L	9.00	161.6	-	-	1071	55.5	-	564	<9.00	<9.00	92.7	<9.00	31.99	<9.00
Al	µg/L	1.00	375.3	-	-	314.3	1971	-	1577	77.4	<1	1761	44.89	1042	446
As	µg/L	8.00	8.67	-	-	11.9	4.58	-	9	10.5	8	8.8	8	10.6	8
Cd	µg/L	0.20	<0.2	-	-	<0.2	<0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ni	µg/L	0.60	<0.6	-	-	<0.6	<0.6	-	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Pb	µg/L	8.00	7.09	-	-	17.22	2.89	-	<8.00	<8.00	<8.00	<8.00	<8.00	<8.00	<8.00
Cu	µg/L	0.60	63.5	-	-	13.11	<0.60	-	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Cr	µg/L	0.50	<0.5	-	-	<0.5	<0.5	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Hg	µg/L	5.00	<5.00	-	-	<5.00	<5.00	-	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Zn	µg/L	0.40	691	-	-	4972	1881	-	1416	47.67	<0.4	3630	64.4	1091	2095
Co	µg/L	9.00	<9.00	-	-	<9.00	<9.00	-	<9.00	<9.00	<9.00	<9.00	<9.00	<9.00	<9.00

Table 4 Surface Water Sampling Results September 1997 (Round 4) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			11	12	13	14	15	16	17	18	19	20	21	22	23
Inorganics		**mg/L**	**11-4A**	**12-4A**	**13-4A**	**14-4A**	**15-4A**	**16-4A**	**17-4A**	**18-4A**	**19-4A**	**20-4A**	**21-4A**	**22-4A**	**23-4A**
Na^+	mg/L	0.03	<	31	52	12.2	13	14	10	-	10	-	10	85	12
K^+	mg/L	0.02	<	1.7	2.6	1.5	1.5	1.52	1.5	-	1.47	-	1.59	1.6	1.4
Ca^{2+}	mg/L	0.01	46	68	93	57	74	75	89	-	53	-	70	101	62
Mg^{2+}	mg/L	0.01	43	47	49	51	53	53	65	-	42	-	65	34	47
NH_4^+	mg/L	0.01	0.54	0.82	1.26	0.9	0.82	0.5	1.22	-	0.86	-	1.4	0.86	0.82
NO_2^-	mg/L	0.01	0.06	0.06	0.11	0.07	0.06	0.05	0.06	-	0.06	-	0.07	0.08	0.07
NO_3^-	mg/L	0.01	106	115	256	262	156	115	165	-	109	-	58	152	152
Cl^-	mg/L	10.00	<	<	<	<	<	<	<	-	<	-	<	<	<
SO_4^{2-}	mg/L	0.03	40	93	7.4	75	94	99	135	-	30	-	134	49	36
PO_4^{2-}	mg/L	0.05	<	<	<	0.3	<	<	<	-	<	-	<	<	<
HCO_3^-	mg/L	0.01	143	159	239	159	171	155	224	-	146	-	178	234	161
CO_3^{2-}	mg/L	0.01	17	34	38	31	22	36	10	-	24	-	29	43	19
SiO_2	mg/L	0.05	<	9.8	14	9	8	8	8	-	9	-	9	14	8
Metals		**µg/L**	**11-4B**	**12-4B**	**13-4B**	**14-4B**	**15-4B**	**16-4B**	**17-4B**	**18-5B**	**19-4B**	**20-4B**	**21-4B**	**22-4B**	**23-4B**
Mn	µg/L	0.09	<	<	<	<	<	<	<	-	<	-	<	<	<
Fe (III)	µg/L	100.00	<	<	<	<	<	<	<	-	<	-	<	<	<
Fe Total	µg/L	9.00	<	<	<	<	<	<	<	-	<	-	<	<	<
Al	µg/L	1.00	<	<	<	<	<	<	<	-	<	-	<	<	<
As	µg/L	8.00	0.8	<	0.7	2	1	0.7	2	-	<	-	1.6	1.2	1.3
Cd	µg/L	0.20	<	<	<	<	<	<	<	-	<	-	<	<	<
Ni	µg/L	0.60	<	<	<	<	<	<	<	-	<	-	<	<	<
Pb	µg/L	8.00	<	<	<	<	<	<	<	-	<	-	<	<	<
Cu	µg/L	0.60	<	<	<	<	<	<	<	-	<	-	<	<	<
Cr	µg/L	0.50	<	<	<	<	<	<	<	-	<	-	<	<	<
Hg	µg/L	5.00	<	10	4	4	2	1	3	-	3	-	<	<	<
Zn	µg/L	0.40	<	<	<	<	<	<	<	-	<	-	<	<	<
Co	µg/L	9.00	<	<	<	15	<	<	<	-	<	-	<	<	<

Table 4 Surface Water Sampling Results September 1997 (Round 4) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			24	25	26	27	28	29	30	31	32	33	34	35	36
Inorganics		**mg/L**	**24-4A**	**25-4A**	**26-4A**	**27-4A**	**28-4A**	**29-4A**	**30-4A**	**31-4A**	**32-4A**	**33-4A**	**34-4A**	**35-4A**	**36-4A**
Na^+	mg/L	0.03	-	-	69	114	-	-	-	-	-	-	-	-	12
K^+	mg/L	0.02	-	-	3.1	5.1	-	-	-	-	-	-	-	-	1.3
Ca^{2+}	mg/L	0.01	-	-	112	135	-	-	-	-	-	-	-	-	67
Mg^{2+}	mg/L	0.01	-	-	82	93	-	-	-	-	-	-	-	-	66
NH_4^+	mg/L	0.01	-	-	2	2.3	-	-	-	-	-	-	-	-	1.06
NO_2^-	mg/L	0.01	-	-	0.09	0.09	-	-	-	-	-	-	-	-	0.1
NO_3^-	mg/L	0.01	-	-	171	45	-	-	-	-	-	-	-	-	119
Cl^-	mg/L	10.00	<	<	<	<	<	<	<	<	<	<	<	<	<
SO_4^{2-}	mg/L	0.03	-	-	366	640	-	-	-	-	-	-	-	-	27
PO_4^{2-}	mg/L	0.05	-	-	<	<	-	-	-	-	-	-	-	-	<
HCO_3^-	mg/L	0.01	-	-	219	219	-	-	-	-	-	-	-	-	219
CO_3^{2-}	mg/L	0.01	-	-	19	<	-	-	-	-	-	-	-	-	29
SiO_2	mg/L	0.05	-	-	12	12	-	-	-	-	-	-	-	-	10
Metals		**µg/L**	**24-4B**	**25-4B**	**26-4B**	**27-4B**	**28-4B**	**29-4B**	**30-4B**	**31-4B**	**32-4B**	**33-4B**	**34-4B**	**35-4B**	**36-4B**
Mn	µg/L	0.09	-	-	<	<	-	-	-	-	-	-	-	-	<
Fe (III)	µg/L	100.00	<	<	<	<	<	<	<	<	<	<	<	<	<
Fe Total	µg/L	9.00	-	-	<	<	-	-	-	-	-	-	-	-	<
Al	µg/L	1.00	-	-	<	<	-	-	-	-	-	-	-	-	<
As	µg/L	8.00	-	-	1.6	1.8	-	-	-	-	-	-	-	-	1.4
Cd	µg/L	0.20	-	-	<	<	-	-	-	-	-	-	-	-	<
Ni	µg/L	0.60	-	-	<	<	-	-	-	-	-	-	-	-	<
Pb	µg/L	8.00	-	-	<	<	-	-	-	-	-	-	-	-	<
Cu	µg/L	0.60	-	-	<	<	-	-	-	-	-	-	-	-	<
Cr	µg/L	0.50	-	-	<	<	-	-	-	-	-	-	-	-	<
Hg	µg/L	5.00	-	-	1.8	4	-	-	-	-	-	-	-	-	3
Zn	µg/L	0.40	-	-	<	<	-	-	-	-	-	-	-	-	<
Co	µg/L	9.00	-	-	<	<	-	-	-	-	-	-	-	-	<

Table 4 Surface Water Sampling Results September 1997 (Round 4) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			37	38	39	40	41	42	43	44	45	46	47	48	49
Inorganics		**mg/L**	**37-4A**	**38-4A**	**39-4A**	**40-4A**	**41-4A**	**42-4A**	**43-4A**	**44-4A**	**45-4A**	**46-4A**	**47-4A**	**48-4A**	**49-4A**
Na^+	mg/L	0.03	-	16	10	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	-	1.7	1.3	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	-	80	48	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	-	60	36	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	-	1.32	0.7	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	0.07	0.08	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	94	162	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	<	<	<	<	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	-	90	27	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	-	<	<	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	-	180	107	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	-	43	26	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	-	10	8	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**37-4B**	**38-4B**	**39-4B**	**40-4B**	**41-4B**	**42-4B**	**43-4B**	**44-4B**	**45-4B**	**46-4B**	**47-4B**	**48-4B**	**49-4B**
Mn	µg/L	0.09	-	<	<	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	<	<	<	<	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	-	<	<	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	-	<	<	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	-	3	1.5	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	-	<	<	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	-	<	<	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	-	<	<	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	-	<	<	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	-	<	<	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	-	2	1.9	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	-	<	<	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	-	<	<	-	-	-	-	-	-	-	-	-	-

Table 4 Surface Water Sampling Results September 1997 (Round 4) (continued)

Analysis		Detection Limits	Quality Assurance Samples										
			50	51	52	53	54	55	56	57	58	59	60
Inorganics		**mg/L**	**50-4A**	**51-4A**	**52-4A**	**53-4A**	**54-4A**	**55-4A**	**56-4A**	**57-4A**	**58-4A**	**59-4A**	**60-4A**
Na^+	mg/L	0.03	49	10	10	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	2.5	1.6	1.6	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	88	73	84	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	0.16	64	63	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	1.28	1.26	1.26	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	0.09	0.08	0.06	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	101	82	158	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	<	<	<	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	3.6	67	86	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	<	<	<	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	244	219	229	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	24	19	7.2	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	0.54	<	<	-	-	-	-	-	-	-	-
Metals		**µg/L**	**50-4B**	**51-4B**	**52-4B**	**53-4B**	**54-4B**	**55-4B**	**56-4B**	**57-4B**	**58-4B**	**59-4B**	**60-4B**
Mn	µg/L	0.09	<	<	<	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	<	<	<	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	<	<	<	-	-	-	-	-	-	-	-
Al	µg/L	1.00	<	<	<	-	-	-	-	-	-	-	-
As	µg/L	8.00	2	2	1.6	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	<	<	<	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	<	<	<	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	<	<	<	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	<	<	<	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	<	<	<	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	1.9	1.3	1	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	<	<	<	-	-	-	-	-	-	-	-
Co	µg/L	9.00	<	<	<	-	-	-	-	-	-	-	-

Table 4 Surface Water Sampling Results September 1997 (Round 4) (continued)

Analysis		Detection Limits	Fungurume Wells										Tenke Wells		
			101	102	103	104	105	106	107	108	109	110	111	112	113
Inorganics		**mg/L**	**101-4A**	**102-4A**	**103-4A**	**104-4A**	**105-4A**	**106-4A**	**107-4A**	**108-4A**	**109-4A**	**110-4A**	**111-4A**	**112-4A**	**113-4A**
Na^+	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**101-4B**	**102-4B**	**103-4B**	**104-4B**	**105-4B**	**106-4B**	**107-4B**	**108-4B**	**109-4B**	**110-4B**	**111-4B**	**112-4B**	**113-4B**
Mn	µg/L	0.09	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Al	µg/L	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	-	-	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L	9.00	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 5 Surface Water Sampling Results October 1997 (Round 5)

Analysis		Detection Limits	Water Supply Infrastructure						Watercourse Sampling Points						
			Borehole 1	Reservoirs 2		Distribution System 3			4	5	6	7	8	9	10
Inorganics		**mg/L**	**1-5A**	**2.1-5A**	**2.2-5A**	**3.1-5A**	**3.2-5A**	**3.3-5A**	**4-5A**	**5-5A**	**6-5A**	**7-5A**	**8-5A**	**9-5A**	**10-5A**
Na^+	mg/L	0.03	<	<	<	<	<	<	812	12	34	<	<	<	28
K^+	mg/L	0.02	1.6	1.6	1.6	1.5	1.5	1.6	4.3	59	62	1.3	1.4	1.3	1.7
Ca^{2+}	mg/L	0.01	70	69	69	68	69	69	160	61	62	67	68	55	62
Mg^{2+}	mg/L	0.01	65	64	64	63	63	64	112	52	39	54	53	46	44
NH_4^+	mg/L	0.01	0.64	0.5	0.5	0.7	0.88	0.44	1.52	1.16	0.58	1.28	1.18	0.58	1.2
NO_2^-	mg/L	0.01	0.1	0.08	0.08	<	0.08	0.02	0.1	0.1	0.04	0.08	0.02	0.1	0.04
NO_3^-	mg/L	0.01	217	204	204	156	144	291	142	254	31	37	43	37	18
Cl^-	mg/L	10.00	7.8	7.2	7.2	7.2	7.2	7.8	7.2	7.2	4.2	7.8	9	7.8	9
SO_4^{2-}	mg/L	0.03	64	63	63	63	63	64	714	84	72	33	118	64	75
PO_4^{2-}	mg/L	0.05	<	<	<	<	<	<	<	<	<	<	<	<	<
HCO_3^-	mg/L	0.01	239	233	233	232	243	235	194	180	166	202	166	143	156
CO_3^{2-}	mg/L	0.01	<	2.4	2.4	3.6	<	<	<	6	<	10.8	15.6	18	16.8
SiO_2	mg/L	0.05	<	<	<	<	<	<	8.7	<	7.1	<	<	<	6.7
Metals		**µg/L**	**1-5B**	**2-5B**	**2-5B**	**3.1-5B**	**3.2-5B**	**3.3-5B**	**4-5B**	**5-5B**	**6-5B**	**7-5B**	**8-5B**	**9-5B**	**10-5B**
Mn	µg/L	0.09	0.44	<	<	<	<	<	576	16	64	21	4.7	8.5	12
Fe (III)	µg/L	100.00	<	<	<	<	<	<	<	<	160	<	<	<	<
Fe Total	µg/L	9.00	<	<	<	<	<	<	42	<	<	27	<	<	<
Al	µg/L	1.00	80	<	<	<	4	2.7	12	41	141	61	157	24	2.7
As	µg/L	8.00	<	8	8	<	<	<	<	<	<	<	<	<	8.5
Cd	µg/L	0.20	<	<	<	<	<	<	<	<	<	<	<	<	<
Ni	µg/L	0.60	<	<	<	<	<	<	<	<	<	<	<	<	<
Pb	µg/L	8.00	<	<	<	<	12	<	<	<	<	<	<	<	<
Cu	µg/L	0.60	19	20	20	23	25	20	<	0.92	<	<	<	<	<
Cr	µg/L	0.50	<	<	<	<	<	<	<	<	<	<	<	<	<
Hg	µg/L	5.00	15	<	<	<	<	<	<	<	<	<	<	<	<
Zn	µg/L	0.40	33	33	33	1057	1103	48	<	<	<	<	<	<	<
Co	µg/L	9.00	<	<	<	<	<	<	<	<	<	<	<	<	<

Table 5 Surface Water Sampling Results October 1997 (Round 5) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			11	12	13	14	15	16	17	18	19	20	21	22	23
Inorganics		**mg/L**	**11-5A**	**12-5A**	**13-5A**	**14-5A**	**15-5A**	**16-5A**	**17-5A**	**18-5A**	**19-5A**	**20-5A**	**21-5A**	**22-5A**	**23-5A**
Na^+	mg/L	0.03	<	28	48	<	<	10	<	-	<	-	<	76	<
K^+	mg/L	0.02	1.2	1.6	2.2	1.4	1.5	1.4	1.5	-	1.6	-	1.6	1.9	1.4
Ca^{2+}	mg/L	0.01	43	62	87	56	59	59	80	-	69	-	69	97	49
Mg^{2+}	mg/L	0.01	43	44	47	49	53	53	64	-	65	-	65	33	45
NH_4^+	mg/L	0.01	0.58	0.64	0.82	1.1	1.02	0.6	0.86	-	0.66	-	0.66	0.5	0.8
NO_2^-	mg/L	0.01	0.04	0.3	0.02	0.02	0.02	<	0.1	-	0.02	-	0.02	<	0.04
NO_3^-	mg/L	0.01	111	124	130	86	124	365	229	-	192	-	192	68	161
Cl^-	mg/L	10.00	8.4	8.4	8.4	9	8.4	7.8	7.8	-	8.4	-	8.4	7.8	9.6
SO_4^{2-}	mg/L	0.03	34	79	2	59	64	71	115	-	123	-	123	31	31
PO_4^{2-}	mg/L	0.05	<	<	<	<	<	<	<	-	<	-	<	<	<
HCO_3^-	mg/L	0.01	130	130	215	152	176	159	226	-	183	-	183	212	148
CO_3^{2-}	mg/L	0.01	15.6	25.2	22.8	16.8	8.4	15.6	4.8	-	15.6	-	15.6	4.8	19.2
SiO_2	mg/L	0.05	<	7.1	11	<	9.7	9.5	9.3	-	10	-	10	17	8.7
Metals		**µg/L**	**11-5B**	**12-5B**	**13-5B**	**14-5B**	**15-5B**	**16-5B**	**17-5A**	**18-5B**	**19-5B**	**20-5B**	**21-5B**	**22-5B**	**23-5B**
Mn	µg/L	0.09	7.1	12.3	248	8	7.6	11.4	7.2	-	5.9	-	5.9	62	0.6
Fe (III)	µg/L	100.00	<	<	<	<	<	<	100	-	<	-	<	<	180
Fe Total	µg/L	9.00	<	<	1.7	<	<	<	<	-	<	-	<	<	<
Al	µg/L	1.00	7.3	4.7	45	7.5	6.8	6.9	24	-	4.8	-	4.8	37	149
As	µg/L	8.00	<	8.5	8.9	<	<	<	<	-	<	-	<	10	<
Cd	µg/L	0.20	<	<	<	<	<	<	<	-	<	-	<	<	<
Ni	µg/L	0.60	<	<	<	<	<	<	<	-	<	-	<	<	<
Pb	µg/L	8.00	<	<	<	<	<	<	<	-	<	-	<	<	<
Cu	µg/L	0.60	3.8	<	1.3	<	1.3	0.48	3.9	-	2.1	-	2.1	<	56
Cr	µg/L	0.50	<	<	<	<	<	<	<	-	<	-	<	<	<
Hg	µg/L	5.00	<	<	<	<	<	<	<	-	<	-	<	<	<
Zn	µg/L	0.40	<	<	<	<	<	<	<	-	65	-	65	<	<
Co	µg/L	9.00	<	<	<	<	<	<	<	-	<	-	<	<	<

Table 5 Surface Water Sampling Results October 1997 (Round 5) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			24	25	26	27	28	29	30	31	32	33	34	35	36
Inorganics		**mg/L**	**24-5A**	**25-5A**	**26-5A**	**27-5A**	**28-5A**	**29-5A**	**30-5A**	**31-5A**	**32-5A**	**33-5A**	**34-5A**	**35-5A**	**36-5A**
Na^+	mg/L	0.03	-	<	818	624	-	-	-	-	-	-	-	-	13
K^+	mg/L	0.02	-	1.4	4.4	3	-	-	-	-	-	-	-	-	1.3
Ca^{2+}	mg/L	0.01	-	24	158	116	-	-	-	-	-	-	-	-	65
Mg^{2+}	mg/L	0.01	-	21	111	74	-	-	-	-	-	-	-	-	66
NH_4^+	mg/L	0.01	-	1.04	1.56	1.52	-	-	-	-	-	-	-	-	0.46
NO_2^-	mg/L	0.01	-	<	0.08	0.06	-	-	-	-	-	-	-	-	0.06
NO_3^-	mg/L	0.01	-	161	111	167	-	-	-	-	-	-	-	-	204
Cl^-	mg/L	10.00	-	8.4	7.2	1.8	-	-	-	-	-	-	-	-	2.4
SO_4^{2-}	mg/L	0.03	-	1	567	324	-	-	-	-	-	-	-	-	22
PO_4^{2-}	mg/L	0.05	-	<	<	<	-	-	-	-	-	-	-	-	<
HCO_3^-	mg/L	0.01	-	94	191	185	-	-	-	-	-	-	-	-	212
CO_3^{2-}	mg/L	0.01	-	<	2.4	16.8	-	-	-	-	-	-	-	-	15.6
SiO_2	mg/L	0.05	-	5.6	13	16	-	-	-	-	-	-	-	-	12
Metals		**µg/L**	**24-5B**	**25-5B**	**26-5B**	**27-5B**	**28-5B**	**29-5B**	**30-5B**	**31-5B**	**32-5B**	**33-5B**	**34-5B**	**35-5B**	**36-5B**
Mn	µg/L	0.09	-	4533	938	329	-	-	-	-	-	-	-	-	1
Fe (III)	µg/L	100.00	-	<	<	<	-	-	-	-	-	-	-	-	<
Fe Total	µg/L	9.00	-	15	9.3	<	-	-	-	-	-	-	-	-	<
Al	µg/L	1.00	-	<	83	2.1	-	-	-	-	-	-	-	-	9.8
As	µg/L	8.00	-	<	13.2	<	-	-	-	-	-	-	-	-	<
Cd	µg/L	0.20	-	<	<	<	-	-	-	-	-	-	-	-	<
Ni	µg/L	0.60	-	<	<	<	-	-	-	-	-	-	-	-	<
Pb	µg/L	8.00	-	<	<	<	-	-	-	-	-	-	-	-	<
Cu	µg/L	0.60	-	<	0.2	1.6	-	-	-	-	-	-	-	-	<
Cr	µg/L	0.50	-	<	<	<	-	-	-	-	-	-	-	-	<
Hg	µg/L	5.00	-	<	<	<	-	-	-	-	-	-	-	-	<
Zn	µg/L	0.40	-	<	<	<	-	-	-	-	-	-	-	-	<
Co	µg/L	9.00	-	<	<	<	-	-	-	-	-	-	-	-	<

Table 5 Surface Water Sampling Results October 1997 (Round 5) (continued)

Analysis		Detection Limits	Watercourse Sampling Points												
			37	38	39	40	41	42	43	44	45	46	47	48	49
Inorganics		**mg/L**	**37-5A**	**38-5A**	**39-5A**	**40-5A**	**41-5A**	**42-5A**	**43-5A**	**44-5A**	**45-5A**	**46-5A**	**47-5A**	**48-5A**	**49-5A**
Na^+	mg/L	0.03	<	15	<	24	87	62	-	-	-	-	-	-	-
K^+	mg/L	0.02	1.4	1.6	1.3	1.3	1.7	1.6	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	69	72	41	36	67	69	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	63	59	36	34	58	60	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	0.9	0.64	0.42	0.44	0.7	0.8	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	0.02	0.06	0.06	0.08	0.08	0.12	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	111	111	62	124	142	223	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	2.4	3.6	7.2	7.2	7.2	1.8	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	101	69	6.2	6.5	112	122	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	<	<	<	<	<	<	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	169	180	122	32	154	160	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	24	25.2	8.4	9.6	19.2	20.4	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	9.5	12	9.3	16	11	12	-	-	-	-	-	-	-
Metals		**µg/L**	**37-5B**	**38-5B**	**39-5B**	**40-5B**	**41-5B**	**42-5B**	**43-5B**	**44-5B**	**45-5B**	**46-5B**	**47-5B**	**48-5B**	**49-5B**
Mn	µg/L	0.09	12	15	8.9	556	60	27	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	<	<	<	<	<	<	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	<	<	<	<	<	<	-	-	-	-	-	-	-
Al	µg/L	1.00	153	215	167	368	72	59	-	-	-	-	-	-	-
As	µg/L	8.00	<	<	<	<	<	11	-	-	-	-	-	-	-
Cd	µg/L	0.20	<	<	<	<	<	<	-	-	-	-	-	-	-
Ni	µg/L	0.60	<	<	<	<	<	<	-	-	-	-	-	-	-
Pb	µg/L	8.00	<	<	<	<	<	<	-	-	-	-	-	-	-
Cu	µg/L	0.60	<	<	2.4	0.8	0.8	12	-	-	-	-	-	-	-
Cr	µg/L	0.50	<	<	<	<	<	<	-	-	-	-	-	-	-
Hg	µg/L	5.00	<	<	<	<	<	<	-	-	-	-	-	-	-
Zn	µg/L	0.40	<	<	<	<	<	38	-	-	-	-	-	-	-
Co	µg/L	9.00	<	<	<	<	13	10	-	-	-	-	-	-	-

Table 5 Surface Water Sampling Results October 1997 (Round 5) (continued)

Analysis		Detection Limits	Quality Assurance Samples										
			50	51	52	53	54	55	56	57	58	59	60
Inorganics		**mg/L**	**50-5A**	**51-5A**	**52-5A**	**53-5A**	**54-5A**	**55-5A**	**56-5A**	**57-5A**	**58-5A**	**59-5A**	**60-5A**
Na^+	mg/L	0.03	<	<	<	-	-	-	-	-	-	-	-
K^+	mg/L	0.02	0.8	1.6	0.8	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L	0.01	<	71	<	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L	0.01	0.2	65	0.3	-	-	-	-	-	-	-	-
NH_4^+	mg/L	0.01	0.14	0.98	0.22	-	-	-	-	-	-	-	-
NO_2^-	mg/L	0.01	0.12	0.1	0.08	-	-	-	-	-	-	-	-
NO_3^-	mg/L	0.01	210	272	223	-	-	-	-	-	-	-	-
Cl^-	mg/L	10.00	1.8	2.4	4.2	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.03	<	123	0.5	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L	0.05	<	<	<	-	-	-	-	-	-	-	-
HCO_3^-	mg/L	0.01	2.4	183	2.4	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L	0.01	<	14.4	0.02	-	-	-	-	-	-	-	-
SiO_2	mg/L	0.05	<	11	<	-	-	-	-	-	-	-	-
Metals		**µg/L**	**50-5B**	**51-5B**	**52-5B**	**53-5B**	**54-5B**	**55-5B**	**56-5B**	**57-5B**	**58-5B**	**59-5B**	**60-5B**
Mn	µg/L	0.09	<	5.6	<	-	-	-	-	-	-	-	-
Fe (III)	µg/L	100.00	<	<	<	-	-	-	-	-	-	-	-
Fe Total	µg/L	9.00	<	<	<	-	-	-	-	-	-	-	-
Al	µg/L	1.00	<	25	26	-	-	-	-	-	-	-	-
As	µg/L	8.00	<	8.8	<	-	-	-	-	-	-	-	-
Cd	µg/L	0.20	<	<	<	-	-	-	-	-	-	-	-
Ni	µg/L	0.60	<	<	<	-	-	-	-	-	-	-	-
Pb	µg/L	8.00	<	<	<	-	-	-	-	-	-	-	-
Cu	µg/L	0.60	<	0.7	3.6	-	-	-	-	-	-	-	-
Cr	µg/L	0.50	<	<	<	-	-	-	-	-	-	-	-
Hg	µg/L	5.00	<	<	<	-	-	-	-	-	-	-	-
Zn	µg/L	0.40	<	27	147	-	-	-	-	-	-	-	-
Co	µg/L	9.00	<	<	<	-	-	-	-	-	-	-	-

Table 5 Surface Water Sampling Results October 1997 (Round 5) (continued)

Analysis		Detection Limits	Fungurume Wells										Tenke Wells		
			101	102	103	104	105	106	107	108	109	110	111	112	113
Inorganics		**mg/L**	**101-5A**	**102-5A**	**103-5A**	**104-5A**	**105-5A**	**106-5A**	**107-5A**	**108-5A**	**109-5A**	**110-5A**	**111-5A**	**112-5A**	**113-5A**
Na^+	mg/L	**0.03**	<	14	12	10	15	11	25	60	32	-	12	14	-
K^+	mg/L	**0.02**	1.7	1.6	1.6	1.2	1	1.4	1.6	2	1.2	-	1.5	1.5	-
Ca^{2+}	mg/L	**0.01**	5.4	69	58	43	37	6.3	<	6.2	30	-	46	0.3	-
Mg^{2+}	mg/L	**0.01**	9.6	50	43	34	30	14	3.9	19	35	-	32	2.3	-
NH_4^+	mg/L	**0.01**	0.3	0.44	0.54	0.44	0.31	0.38	0.3	0.68	0.68	-	0.46	1.3	-
NO_2^-	mg/L	**0.01**	0.22	0.2	0.12	0.16	0.18	0.28	1.2	0.52	0.16	-	0.38	0.16	-
NO_3^-	mg/L	**0.01**	148	210	248	173	272	223	217	192	173	-	229	248	-
Cl^-	mg/L	**10.00**	4.8	3	3	3	3	2.4	3	2.4	3.6	-	4.8	2.4	-
SO_4^{2-}	mg/L	**0.03**	2.5	92	42	49	34	5	0.7	18	48	-	4.1	1.5	-
PO_4^{2-}	mg/L	**0.05**	<	<	<	<	<	<	<	<	<	-	<	<	-
HCO_3^-	mg/L	**0.01**	37	59	146	132	74	24	4.9	12	122	-	126	12	-
CO_3^{2-}	mg/L	**0.01**	<	<	<	<	<	<	<	<	<	-	12	<	-
SiO_2	mg/L	**0.05**	9.6	9.3	10	8.7	13	12	11	23	20	-	13	<	-
Metals		**µg/L**	**101-5B**	**102-5B**	**103-5B**	**104-5B**	**105-5B**	**106-5B**	**107-5B**	**108-5B**	**109-5B**	**110-5B**	**111-5B**	**112-5B**	**113-5B**
Mn	µg/L	**0.09**	6.2	54	2747	49	6.4	22	79	229	261	-	7.2	34	-
Fe (III)	µg/L	**100.00**	<	<	<	<	<	<	<	<	<	-	<	<	-
Fe Total	µg/L	**9.00**	<	<	209	<	<	<	<	14	<	-	<	49	-
Al	µg/L	**1.00**	121	175	251	39	8.5	29	239	32	109	-	294	691	-
As	µg/L	**8.00**	<	<	8.7	<	<	<	<	<	8.5	-	<	<	-
Cd	µg/L	**0.20**	<	<	<	<	<	<	<	<	<	-	<	<	-
Ni	µg/L	**0.60**	<	<	<	<	<	<	18	28	<	-	<	<	-
Pb	µg/L	**8.00**	<	<	<	<	<	<	<	<	<	-	<	<	-
Cu	µg/L	**0.60**	<	<	<	<	<	1.7	12	2.6	1.7	-	<	1.4	-
Cr	µg/L	**0.50**	<	<	<	<	<	<	<	<	<	-	<	<	-
Hg	µg/L	**5.00**	<	<	<	<	<	<	<	<	<	-	<	<	-
Zn	µg/L	**0.40**	<	<	<	<	<	2.8	20	27	17	-	35	17	-
Co	µg/L	**9.00**	<	<	12	<	<	<	84	52	<	-	<	<	-

Table 6 Surface Water Sampling Results December 1997 (Round 6)

Analysis		Detection Limits	Water Supply Infrastructure						Watercourse Sampling Points								
			Borehole	Reservoirs		Distribution System											
			1	2.1	2.2	3.1	3.2	3.3	4	5	6	7	8	9	10	11	12
Inorganics		**mg/L**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**
Na^+	mg/L		-	-	-	-	-	-	56	11	12	-	-	-	11	-	15
K^+	mg/L		1.7	1.7	-	1.7	-	-	1.4	1.3	1.2	1.4	1.5	1.4	4.8	1.2	1.1
Ca^{2+}	mg/L		56	55	-	55	-	-	15	13.3	11	54	56	37	9.9	15	18
Mg^{2+}	mg/L		50	50	-	50	-	-	7.4	8.7	5	43	42	31	4.8	14	10
NH_4^+	mg/L		0.2	0.2	-	0.2	-	-	0.2	0.2	0.2	0.2	0.2	0.2	0.18	0.2	0.2
NO_2^-	mg/L		0.06	-	-		-	-	0.06	0.04	0.04	0.02	-	-	0.08	0.04	0.06
NO_3^-	mg/L		46	46	-	62	-	-	49	71	120	111	176	24	89	54	67
Cl^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L		37	38	-	37	-	-	15	9.1	2.9	22	73	31	3.5	7.3	7.4
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		219.7	219	-	216	-	-	46.4	48.8	41.5	175.7	180.6	141.6	29.3	65.9	64.7
CO_3^{2-}	mg/L		14.4	19.2	-	26.4	-	-	2.4	2.4		28.8	14.4	4.8	-	-	2.4
SiO_2	mg/L		7.9	7.9	-	7.8	-	-	7.3	7.2	8.1	7.3	7.9	6.6	6.5	5.8	7.9
Metals		**µg/L**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**
Mn	µg/L		-	-	-	3.2	-	-	11	15	13	25	0.4	18	8.6	1.9	6.8
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	-	-	-	-	-	-	-	-	5.2	-	-	-	-	-
Al	mg/L			46	-	408	-	-	10	16	-	-	-	65	37	-	-
As	µg/L		12	12	-	8.1	-	-	12	10	-	12	10	-	-	12	9.7
Cd	µg/L		0.8	0.7	-	1.3	-	-	0.7	0.8	0.6	0.7	0.8	0.8	0.9	0.8	0.7
Ni	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		4.6	6.5	-	42	-	-	-	-	-	-	-	-	-	3.1	-
Cr	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L		3.9	11	-	6521	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6 Surface Water Sampling Results December 1997 (Round 6) (continued)

Analysis		Detection Limits	Watercourse Sampling Points														
			13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Inorganics		**mg/L**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**
Na^+	mg/L		12	11	12	12	-	12	-	13	-	12	-	-	-	37	48
K^+	mg/L		1.2	1.3	1.4	1.3	-	1.1	-	1.2	1.8	1.2	1.5	1	-	1.4	1.3
Ca^{2+}	mg/L		13	13	15	18	-	3.9	-	14	58	13	47	5.4	-	15	14
Mg^{2+}	mg/L		6.4	8.4	10	12	-	4.7	-	6.6	49	7.3	41	5.3	-	8.2	7.2
NH_4^+	mg/L		0.06	0.22	0.2	0.18	-	0.2	-	0.14	0.4	0.2	0.22	0.2	-	0.2	0.2
NO_2^-	mg/L		0.08	0.06	0.04	0.04	-	0.04	-	0.06	0.04	0.06	0.04	0.06	-	0.08	-
NO_3^-	mg/L		66	46	63	105	-	37	-	61	49	31	99	62	-	31	99
Cl^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L		1.2	7	10	11	-	6	-	1.3	81	2.5	23	0.7	-	14	12
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		41.5	48.8	48.8	68.3	-	29.3	-	50	158.9	43.9	148.9	30.5	-	32.9	42.7
CO_3^{2-}	mg/L		-	-	10	-	-	-	-	-	21.6	7.2	33.6	2.4	-	16.8	4.8
SiO_2	mg/L		8.2	6.7	6.6	7.5	-	8.9	-	8.4	8.4	8.1	9.6	5.5	-	7.5	7.6
Metals		**µg/L**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**
Mn	µg/L		20	20	34	7.6	-	60	-	29	6.3	16	1.7	1	-	15	12
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Al	mg/L		141	-	1160	17	-	2.7	-	0.9	118	16	-	-	-	12	16
As	µg/L		13	11	7.3	9.8	-	9.9	-	11	13	10	10	9.8	-	9.2	9.3
Cd	µg/L		0.9	0.7	0.7	0.8	-	0.8	-	0.8	0.8	0.6	0.9	0.7	-	0.7	0.7
Ni	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6 Surface Water Sampling Results December 1997 (Round 6) (continued)

Analysis		Detection Limits	Watercourse Sampling Points														
			28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Inorganics		**mg/L**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**
Na^+	mg/L		35	-	-	-	-	-	-	-	-	-	10	25	-	-	-
K^+	mg/L		1.3	-	-	1.1	-	1.8	-	-	-	-	1.2	1.3	-	-	-
Ca^{2+}	mg/L		12	-	-	22	-	37	-	-	-	-	25	29	-	-	-
Mg^{2+}	mg/L		7	-	-	26	-	31	-	-	-	-	18	26	-	-	-
NH_4^+	mg/L		0.12	-	-	0.2	-	0.2	-	-	-	-	0.08	0.24	-	-	-
NO_2^-	mg/L		0.1	-	-	0.06	-	0.04	-	-	-	-	0.04	0.04	-	-	-
NO_3^-	mg/L		34	-	-	43	-	68	-	-	-	-	68	18	-	-	-
Cl^-	mg/L			-	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L		8.3	-	-	6	-	13	-	-	-	-	1.9	3.7	-	-	-
PO_4^{2-}	mg/L			-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		36.6	-	-	96.4	-	115.9	-	-	-	-	80.5	67.1	-	-	-
CO_3^{2-}	mg/L		2.4	-	-	16.8	-	38.4	-	-	-	-	19.2	76.8	-	-	-
SiO_2	mg/L		7.1	-	-	5.6	-	8.6	-	-	-	-	7.9	13	-	-	-
Metals		**µg/L**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**
Mn	µg/L		14	-	-	65	-	11	-	-	-	-	13	599	-	-	-
Fe (III)	mg/L		-	-	-	140	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	-	-	108	-	-	-	-	-	-	-	-	-	-	-
Al	mg/L		13	-	-	-	-	-	-	-	-	-	92	34	-	-	-
As	µg/L		8.4	-	-	11	-	-	-	-	-	-	9.4	-	-	-	-
Cd	µg/L		0.7	-	-	0.8	-	0.7	-	-	-	-	0.7	0.7	-	-	-
Ni	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6 Surface Water Sampling Results December 1997 (Round 6) (continued)

Analysis		Detection Limits	Watercourse Sampling Points								Trip Blanks				
			43	44	45	46	47	48	49	50	51	52	53	54	55
Inorganics		**mg/L**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**
Na^+	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**
Mn	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Al	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6 Surface Water Sampling Results December 1997 (Round 6) (continued)

Analysis		Detection Limits	QA SAMPLES														
			56	57	58	59	60	61	62	63	64	65	66	67	68	69	70
Inorganics		**mg/L**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**
Na^+	mg/L		11	31	-	-	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L		1.3	1.9	-	-	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L		42	3	-	-	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L		31	3.9	-	-	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L		0.22	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L		0.02	0.21	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		34	43	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L		36	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		117.1	8.5	-	-	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L		21.6		-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		7.4	8.5	-	-	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**
Mn	µg/L		138	120	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Al	mg/L		-	88	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L		8.2		-	-	-	-	-	-	-	-	-	-	-	-	-
Cd	µg/L		0.6	0.7	-	-	-	-	-	-	-	-	-	-	-	-	-
Ni	µg/L		-	29	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		-	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-
Cr	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L		-	135	-	-	-	-	-	-	-	-	-	-	-	-	-
Co	µg/L		-	113	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6 Surface Water Sampling Results December 1997 (Round 6) (continued)

Analysis		Detection Limits	Fungurume Wells										Tenke Wells		
			101	102	103	104	105	106	107	108	109	110	111	112	113
Inorganics		**mg/L**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**	**6A**
Na^+	mg/L		-	-	11	10	-	-	31	83	21	20	10	20	-
K^+	mg/L		1.8	-	1.3	1.8	-	-	1.9	2.6	1	2.5	1.2	2.5	-
Ca^{2+}	mg/L		1.5	-	42	51	-	-	3	13	35	0.2	17	0.2	-
Mg^{2+}	mg/L		5.8	-	31	45	-	-	3.9	16	24	3.4	12	3.4	-
NH_4^+	mg/L		0.2	-	0.2	0.22	-	-	0.2	0.2	0.2	1.16	0.14	1.16	-
NO_2^-	mg/L		0.16	-	0.04	0.04	-	-	0.28	0.21	0.16	0.18	0.08	0.18	-
NO_3^-	mg/L		79	-	34	74	-	-	65	24	93	155	1.8	155	-
Cl^-	mg/L			-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L		1	-	36	32	-	-	0.2	7.5	29	2.7	2.2	2.7	-
PO_4^{2-}	mg/L			-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		12.2	-	120.8	158.6	-	-	9.8	26.8	63.5	17.1	58.6	17.1	-
CO_3^{2-}	mg/L			-	12	50.4	-	-	-	-	24	-	9.6	-	-
SiO_2	mg/L		9	-	7.4	8.9	-	-	8.3	11	9.6	13	9	13	-
Metals		**µg/L**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**	**6B**			**6B**
Mn	µg/L		270	-	138	30	-	-	119	34	4.4	14	-	14	-
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	1820	-	1820	-
Fe Total	mg/L		-	-	-	-	-	-	-	-	-	2692	-	2692	-
Al	mg/L		6.1	-	44	-	-	-	85	11	435	8711	-	8711	-
As	µg/L		11	-	8.9	11	-	-	8.1	8.9	10	8.5	9.8	8.5	-
Cd	µg/L		0.9	-	0.8	0.9	-	-	0.7	0.7	0.8	1	0.7	1	-
Ni	µg/L		-	-	-	-	-	-	29	9.7	-	0.6	-	0.6	-
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		-	-	-	-	-	-	3.9	-	-	14	-	14	-
Cr	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L		28	-	12	1418	-	-	86	19	5.5	26	2.4	26	-
Co	µg/L		9	-	-	-	-	-	107	11	-	-	-	-	-

Table 7 Surface Water Sampling Results January 1998 (Round 7)

Analysis		Detection Limits	Water Supply Infrastructure						Watercourse Sampling Points								
			Borehole	Reservoirs		Distribution System											
			1	2.1	2.2	3.1	3.2	3.3	4	5	6	7	8	9	10	11	12
Inorganics		**mg/L**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**
Na^+	mg/L		1.6	2.2	-	-	-	-	76.1	3.6	4	1.4	1.6	1.2	4	0.8	4
K^+	mg/L		2.1	3	-	-	-	-	1.8	1	0.6	1.7	2	1.2	0.8	0.9	1
Ca^{2+}	mg/L		90.7	69.4	-	-	-	-	57.9	45.1	28.7	84.5	91.5	53.2	25.5	27.1	30.2
Mg^{2+}	mg/L		83.7	82.3	-	-	-	-	26.6	31.3	10.5	70	71	41.8	11.9	20.3	11.8
NH_4^+	mg/L		-	1.35	-	-	-	-	4.95	11.25	3.15	25.2	4.05	3.6	4.95	3.15	7.65
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		1.77	1.16	-	-	-	-	176.46	1.78	0.45	0.67	0.54	2.47	0.59	0.35	1.83
SO_4^{2-}	mg/L		30.05	31.44	-	-	-	-	42.37	19.07	4.13	15.58	55.57	17.06	2.48	2.73	4.69
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		463.6	420.9	-	-	-	-	189.1	189.1	103.7	408.7	384.3	250.1	91.5	140.3	91.5
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		20.9	21.35	-	-	-	-	22.16	20.32	20.37	20.32	20.86	18.14	20.41	15.25	19.96
Metals		**µg/L**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**
Mn	µg/L		-	-	-	-	-	-	98.8	40.68	28.68	80.92	-	12.54	-	-	1.87
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Al	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L		0.484	0.519	-	-	-	-	2.249	0.673	0.787	0.278	0.352	0.43	0.76	0.27	0.787
Cd	µg/L		0.803	0.32	-	-	-	-	0.183	0.107	0.055	0.179	0.056	0.024	-	-	-
Ni	µg/L		0.8	0.71	-	-	-	-	0.02	-	-	0.35	0.79	-	-	-	-
Pb	µg/L		0.819	1.322	-	-	-	-	5.892	0.596	0.725	0.689	0.547	0.721	0.548	1.389	0.787
Cu	µg/L		14.471	7.992	-	-	-	-	2.272	1.944	1.462	4.359	4.489	2.469	2.181	6.015	2.25
Cr	µg/L		0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		0.756	0.825	-	-	-	-	0.741	0.329	0.245	0.234	0.162	0.236	0.277	0.208	0.108
Zn	µg/L		12.138	13.503	-	-	-	-	8.661	3.17	0.735	8.614	9.346	3.945	3.352	3.885	1.756
Co	µg/L		0.48	0.35	-	-	-	-	0.38	0.59	0.17	1.16	0.36	0.26	0.13	0.19	0.11

Table 7 Surface Water Sampling Results January 1998 (Round 7) (continued)

Analysis		Detection Limits	Watercourse Sampling Points														
			13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Inorganics		**mg/L**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**
Na^+	mg/L		6.1	3	2.7	3	1.7	2.4	1.9	67	-	7.2	1.7	0.9	0.7	43.6	82.8
K^+	mg/L		1.5	1.1	1	1.5	2	0.4	2	1.6	-	1.3	1.9	0.8	0.5	2	2
Ca^{2+}	mg/L		38.6	42.9	44.2	47.7	105.3	9.5	65.8	34.5	-	47.9	67.2	11.6	11.4	53.3	56.2
Mg^{2+}	mg/L		13.3	26.1	29.6	29.9	83.8	6.6	53.2	14.4	-	17.6	59.5	6.8	6.6	27.8	22.8
NH_4^+	mg/L		-	6.75	23.4	8.1	-	-	13.1	6.3	-	17.1	-	7.63	3.15	13.5	8.1
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	1.32	2.5
NO_3^-	mg/L		-	-	-	-	-	-	0.173	-	-	-	-	-	-	-	-
Cl^-	mg/L		1.67	1.98	1.34	0.52	0.6	1.1	1.01	1.19	-	1.76	1.68	0.74	0.82	96.26	191.9
SO_4^{2-}	mg/L		0.52	11.13	12.63	13.61	68.5	0.48	11.57	4.72	-	5.81	1.36	0.37	0.31	28.75	32.17
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		152.5	183	189.1	201.3	457.5	48.8	341.6	152.5	-	189.1	359.9	54.9	48.8	201.3	164.7
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		22.33	19.64	19.4	19.55	20	20.66	23.25	21.8	-	23.02	18.7	13.69	13.22	20.49	21.07
Metals		**µg/L**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**
Mn	µg/L		22.6	26.69	10.39	13.89	-	134.12	-	86.21	-	8.51	-	20.71	39.29	75.3	154.19
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Al	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L		0.747	0.552	0.625	0.604	0.506	0.213	0.333	0.902	-	0.819	0.555	0.271	0.247	1.751	2.698
Cd	µg/L		-	0.018	-	0.027	0.033	-	-	0.011	-	-	0.019	-	-	0.04	0.05
Ni	µg/L		-	2.729	-	-	1.584	-	-	0.544	-	-	1.751	0.611	-	1.052	-
Pb	µg/L		0.632	3.397	0.858	0.863	1.312	1.034	0.696	0.639	-	0.886	0.577	0.679	0.524	0.982	0.565
Cu	µg/L		1.201	3.612	1.631	7.154	13.46	14.406	5.679	2.423	-	0.811	59.026	18.1	1.584	5.833	1.8
Cr	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		0.139	0.119	0.123	0.125	0.284	0.203	0.074	0.089	-	0.093	0.095	0.22	0.069	0.113	0.355
Zn	µg/L		0.76	18.968	3.954	4.445	25.6	8.062	3.442	2.824	-	1.362	14.63	7.038	0.446	17.623	6.671
Co	µg/L		0.19	0.5	0.25	0.68	0.87	0.85	0.42	0.53	-	0.15	0.29	0.64	0.13	0.77	0.32

Table 7 Surface Water Sampling Results January 1998 (Round 7) (continued)

Analysis		Detection Limits	Watercourse Sampling Points														
			28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Inorganics		**mg/L**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**
Na^+	mg/L		30.7	-	-	-	-	-	2.5	-	2.6	2.1	-	-	8.4	-	-
K^+	mg/L		1.4	-	-	-	-	-	3.5	-	1.6	1.5	-	-	1.3	-	-
Ca^{2+}	mg/L		44.2	-	-	-	-	-	66	-	89.5	95.3	-	-	48.5	-	-
Mg^{2+}	mg/L		15.8	-	-	-	-	-	49.1	-	83.5	83.5	-	-	41	-	-
NH_4^+	mg/L		15.75	-	-	-	-	-	-	-	5.4	2.7	-	-	4.95	-	-
NO_2^-	mg/L		0.92	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	-	-	0.23	-	-	-	-	-	-	-	-
Cl^-	mg/L		62.21	-	-	-	-	-	2.76	-	0.63	3.56	-	-	0.51	-	-
SO_4^{2-}	mg/L		5.6	-	-	-	-	-	27.43	-	3.81	39.1	-	-	1.36	-	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		170.8	-	-	-	-	-	286.7	-	481.9	475.8	-	-	286.7	-	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		20	-	-	-	-	-	20.45	-	24.07	20.04	-	-	30.29	-	-
Metals		**µg/L**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**
Mn	µg/L		235.75	-	-	-	-	-	62.53	-	31.8	17.79	-	-	436.41	-	-
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-
Al	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L		1.519	-	-	-	-	-	0.788	-	0.496	0.528	-	-	0.32	-	-
Cd	µg/L		0.005	-	-	-	-	-	0.023	-	0.07	0.05	-	-	-	-	-
Ni	µg/L		0.737	-	-	-	-	-	1.334	-	1.227	1.268	-	-	-	-	-
Pb	µg/L		0.577	-	-	-	-	-	1.836	-	0.866	0.477	-	-	0.451	-	-
Cu	µg/L		1.818	-	-	-	-	-	8.437	-	8.906	1.922	-	-	0.557	-	-
Cr	µg/L		-	-	-	-	-	-	-	-	-	2.3	-	-	-	-	-
Hg	µg/L		0.126	-	-	-	-	-	0.062	-	0.132	0.067	-	-	0.022	-	-
Zn	µg/L		4.518	-	-	-	-	-	19.165	-	8.913	6.432	-	-	3.29	-	-
Co	µg/L		0.47	-	-	-	-	-	1.17	-	0.76	0.47	-	-	0.3	-	-

Table 7 Surface Water Sampling Results January 1998 (Round 7) (continued)

Analysis		Detection Limits	Watercourse Sampling Points								Trip Blanks				
			43	44	45	46	47	48	49	50	51	52	53	54	55
Inorganics		**mg/L**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**
Na^+	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**
Mn	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Al	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L		-	-	-	-	-	-	-	-	0.056	0.086	0.083	0.127	0.131
Cd	µg/L		-	-	-	-	-	-	-	-	0.029	0.099	0.039	-	0.064
Ni	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		-	-	-	-	-	-	-	-	14.873	12.965	13.995	17.246	14.076
Cu	µg/L		-	-	-	-	-	-	-	-	1.101	0.445	0.426	0.358	0.354
Cr	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		-	-	-	-	-	-	-	-	0.671	0.143	0.325	0.137	0.076
Zn	µg/L		-	-	-	-	-	-	-	-	10.042	6.438	7.675	10.288	3.381
Co	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-

Table 7 Surface Water Sampling Results January 1998 (Round 7) (continued)

Analysis		Detection Limits	QA Samples														
			56	57	58	59	60	61	62	63	64	65	66	67	68	69	70
Inorganics		**mg/L**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**
Na^+	mg/L		-	-	-	-	-	2.9	2.7	2.3	1.5	1.6	2.3	1.6	2.8	21.3	-
K^+	mg/L		-	-	-	-	-	1.1	0.9	3.2	1.5	1.8	0.5	1.7	0.7	1.6	-
Ca^{2+}	mg/L		-	-	-	-	-	47.1	42.5	66.4	66.8	90.7	9.1	106.6	64.1	25.9	-
Mg^{2+}	mg/L		-	-	-	-	-	29.7	25.6	48.5	60.6	70.6	6.6	84.3	45.6	23.6	-
NH_4^+	mg/L		-	-	-	-	-	7.2	2.25	5.85	4.5	2.25	11.25	5.4	4.5	9.45	-
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	1.33	-
NO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	5.1	175.2	-
Cl^-	mg/L		-	-	-	-	-	1.81	0.47	1.74	0.57	1.96	0.14	2.02	3.38	57.48	-
SO_4^{2-}	mg/L		-	-	-	-	-	14.16	8.83	31.11	1.41	58.35	0.43	67.78	29.46	1.29	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		-	-	-	-	-	207.4	189.1	298.9	372.1	402.6	54.9	469.7	280.6	24.4	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		-	-	-	-	-	19.55	19.55	20.41	18.59	20	20.49	19.55	16.84	21.54	-
Metals		**µg/L**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**
Mn	µg/L		-	-	-	-	-	15.35	15.21	52.32	-	-	141.78	-	-	4.51	-
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-		-
Fe Total	mg/L		-	-	-	-	-	-	-	0.07	0.09	-	0.15	-	0.11	0.02	-
Al	mg/L		-	-	-	-	-	-	-		-	-	-	-	-	-	-
As	µg/L		-	-	-	-	-	0.679	0.674	0.608	0.51	0.501	0.31	0.369	0.136	0.849	-
Cd	µg/L		-	-	-	-	-	0.076	0.062	0.093	0.072	0.059	-	0.037	0.044	0.083	-
Ni	µg/L		-	-	-	-	-	-	-	0.234	1.645	1.428	-	1.179	0.375	8.454	-
Pb	µg/L		-	-	-	-	-	1.022	0.695	0.69	1.092	0.558	0.547	0.658	1.107	3.039	-
Cu	µg/L		-	-	-	-	-	2.275	2.916	5.614	65.783	5.623	5.411	17.168	1.542	13.115	-
Cr	µg/L		-	-	-	-	-	-	-	-	-	0.96	-	0.36	-	-	-
Hg	µg/L		-	-	-	-	-	0.08	0.08	0.051	0.158	0.065	0.05	0.086	0.359	0.367	-
Zn	µg/L		-	-	-	-	-	3.76	11.379	7.912	24.016	9.823	4.247	22.359	28.868	71.971	-
Co	µg/L		-	-	-	-	-	0.38	0.32	0.96	0.53	0.38	0.62	0.78	0.25	3.54	-

Table 7 Surface Water Sampling Results January 1998 (Round 7) (continued)

Analysis		Detection Limits	Fungurume Wells										Tenke Wells		
			101	102	103	104	105	106	107	108	109	110	111	112	113
Inorganics		**mg/L**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**	**7A**
Na^+	mg/L		3.3	3.1	3.2	5.5	4.4	3.5	14.4	51.6	21	-	2.1	10.5	-
K^+	mg/L		2.8	1.4	1.1	2.3	0.3	1.7	3.1	14.9	1.8	-	0.6	7.4	-
Ca^{2+}	mg/L		18.2	60.7	60.7	79.2	43.1	9.3	2	11.8	26.3	-	26	4.4	-
Mg^{2+}	mg/L		6.8	44	45.1	54.7	28.7	12.6	3.8	30.6	23.6	-	13.1	4.5	-
NH_4^+	mg/L		6.3	13.05	8.1	5.4	8.1	10.8	5.4	1.8	2.15	-	9.9	10.8	-
NO_2^-	mg/L		0.28	-	-	2.55	0.8	0.48	0.61	1.45	0.79	-	-	-	-
NO_3^-	mg/L		48.2	-	0.42	59.8	50.06	39.71	67.35	274.56	176.22	-	-	-	-
Cl^-	mg/L		7.63	4.29	6.08	13.64	13.5	5.78	12.1	102.23	56.53	-	0.67	10.32	-
SO_4^{2-}	mg/L		0.45	29.37	29.48	36.22	12.93	1.05	0.1	0.55	1.35	-	0.36	1.25	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		42.7	280.6	280.6	298.9	164.7	54.9	6.1	6.1	18.3	-	122	54.9	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		23.96	18.14	16.79	17.73	24.52	24.28	20.66	23.55	21.39	-	19.55	6.33	-
Metals		**µg/L**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**	**7B**
Mn	µg/L		-	-	-	-	-	3.53	83.64	382.65	10.84	-	-	58.74	-
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	0.05	0.09	0.09	0.05	0.1	0.03	0.06	-	-	0.04	-	-
Al	mg/L		-	-	-	-	-	-	-	-	0.24	-	-	-	-
As	µg/L		0.233	0.208	0.193	0.245	0.307	0.125	0.391	1.905	1.07	-	0.451	0.47	-
Cd	µg/L		-	-	-	0.064	0.053	-	0.094	-	-	-	-	-	-
Ni	µg/L		0.473	0.385	0.333	0.621	-	-	21.885	77.21	8.169	-	-	-	-
Pb	µg/L		0.573	0.681	0.738	0.617	0.517	0.819	5.204	1.249	1.317	-	1.026	0.556	-
Cu	µg/L		1.386	1.138	1.417	1.495	1.274	3.021	14.117	29.513	7.149	-	2.261	5.718	-
Cr	µg/L		-	-	0.21	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		0.057	0.06	0.051	0.053	0.076	0.05	0.015	0.181	0.064	-	0.083	0.371	-
Zn	µg/L		8.143	11.18	27.811	11.478	12.936	16.067	338.5	96.502	42.863	-	38.372	11.657	-
Co	µg/L		0.16	0.2	0.28	0.42	0.21	0.98	96.17	136.93	5.01	-	0.45	0.74	-

Table 8 Surface Water Sampling Results March 1998 (Round 8)

Analysis		Detection Limits	Water Supply Infrastructure						Watercourse Sampling Points								
			Borehole	Reservoirs		Distribution System											
			1	2.1	2.2	3.1	3.2	3.3	4	5	6	7	8	9	10	11	12
Inorganics		**mg/L**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**
Na^+	mg/L		1.4	-	-	-	-	43.7	2.9	2.8	1.5	1.2	0.7	2.6	0.5	2.7	4.7
K^+	mg/L		2.7	-	-	-	-	1.2	1.1	0.5	1.2	1.7	1.3	0.5	0.9	0.5	1.2
Ca^{2+}	mg/L		70.3	-	-	-	-	26.7	19.5	9.4	30.3	52.3	20.8	9	17.4	11.4	12.8
Mg^{2+}	mg/L		62.6	-	-	-	-	18.1	23.5	9.7	31.3	45.3	31.3	9.9	18.8	10.7	11.4
NH_4^+	mg/L		4.32	-	-	-	-	3.96	-	2.16	0.36	0.38	0.41	0.36	0.34	4.68	1.44
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		-	-	-	-	-	72.19	-	-	-	-	-	-	1.29	-	-
SO_4^{2-}	mg/L		30	-	-	-	-	21	15	3	45	42	15	6	9	4.5	4.5
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		469.7	-	-	-	-	134.2	152.5	120.2	337.9	323.3	195.2	61	109.8	67.1	142.4
CO_3^{2-}	mg/L		-	-	-	-	-		-	-	-	-	-	-	-	-	-
SiO_2	mg/L		19.03	-	-	-	-	20.52	18.36	18.46	19.63	19.19	16.23	18.38	13.98	18.25	20.14
Metals		**µg/L**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**
Mn	µg/L		-	-	-	-	-	0.09	0.01	0.12	0.06	0.08	0.1	0.1	0.06	0.08	0.13
Fe (III)	mg/L		-	-	-	-	-	0.09	0.01	0.12	0.06	0.08	0.1	0.1	0.06	0.08	0.13
Fe Total	mg/L		0.01	-	-	-	-	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Al	mg/L		5.332	-	-	-	-	117.181	43.137	46.163	19.517	7.774	18.643	14.377	11.652	22.17	28.379
As	µg/L		1.333	-	-	-	-	2.719	1.494	1.61	1.186	1.235	1.262	1.498	1.179	1.633	1.487
Cd	µg/L		0.322	-	-	-	-	0.292	0.285	0.352	0.315	0.331	0.236	0.184	0.267	0.217	0.249
Ni	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		0.046	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		9.416	-	-	-	-	0.985	0.712	0.1	-	3.247	0.971	0.281	5.971	1.061	-
Cr	µg/L		2.051	-	-	-	-	2.462	1.045	1.556	1.428	2.34	1.574	2.273	1.852	1.468	2.132
Hg	µg/L		0.362	-	-	-	-	0.343	0.101	0.138	0.197	0.154	0.128	0.115	0.154	0.082	0.082
Zn	µg/L		11.802	-	-	-	-	5.022	5.58	0.117	9.736	7.184	1.903	-	34.701	0.846	-
Co	µg/L		0.583	-	-	-	-	0.588	0.683	0.344	0.433	0.483	0.366	0.211	0.424	0.25	0.272

Table 8 Surface Water Sampling Results March 1998 (Round 8) (continued)

Analysis		Detection Limits	Watercourse Sampling Points														
			13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Inorganics		**mg/L**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**
Na^+	mg/L		2.1	-	2.2	-	1.6	1.4	4.7	1.2	5	1.2	0.7	0.5	27.2	42.7	12.9
K^+	mg/L		0.7	-	0.7	-	0.4	2	1.1	1.8	0.9	1.7	0.3	0.4	1	1	0.7
Ca^{2+}	mg/L		19.6	-	14.7	-	4.6	31	12.8	49.5	14.7	47.8	7.4	7.2	24.7	24.6	15.7
Mg^{2+}	mg/L		19.2	-	19.1	-	6.7	40.6	11.5	47.9	14	45.1	8	7.9	19.4	16.5	13.2
NH_4^+	mg/L		0.32	-	0.35	-	0.36	0.4	0.35	0.34	14.41	0.33	0.31	0.34	0.38	0.37	0.36
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	1.11	2.14	0.81
NO_3^-	mg/L		-	-	-	-	-	0.214	-	1.24	-	-	-	-	-	-	-
Cl^-	mg/L		0.7	-	-	-	-	-	-		-	-	-	-	42.89	78.59	15.31
SO_4^{2-}	mg/L		12	-	18	-	6	12	0.01	43.5	6	6	3	3	39	18	9
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		188.1	-	183.7	-	30.5	298.9	165.4	292.8	197.6	372.1	36.6	36.6	134.2	115.9	91.5
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		18.15	-	18.08	-	19.49	21.69	19.98	18.86	20.72	17.31	12.98	12.68	19.2	19.85	18.65
Metals		**µg/L**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**
Mn	µg/L		0.05	-	0.02	-	0.12	0.02	0.03	-	-	0.04	0.02	0.22	0.02	0.05	-
Fe (III)	mg/L		0.05	-	0.02	-	0.12	0.02	0.03	-	-	0.04	0.02	0.22	0.02	0.05	-
Fe Total	mg/L		0.01	-	0.01	-	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Al	mg/L		23.391	-	24.695	-	65.307	13.436	57.536	10.86	15.608	2.767	29.193	43.82	86.025	111.28	135.057
As	µg/L		1.282	-	1.256	-	1.015	1.056	1.289	1.052	1.207	1.078	0.921	0.883	2.033	2.699	1.698
Cd	µg/L		0.066	-	0.008	-	0.052	0.049	0.112	0.13	0.036	0.074	0.053	0.002	0.112	0.126	0.121
Ni	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		0.226	-	1.839	-	0.392		0.299	3.457	0.083	50.371	0.959	-	0.928	0.051	0.967
Cr	µg/L		0.949	-	0.938	-	1.169	1.481	1.843	0.996	1.117	2.942	1.499	1.603	1.564	1.666	0.691
Hg	µg/L		0.108	-	0.109	-	0.075	0.082	0.113	0.109	0.109	0.091	0.114	0.109	0.163	0.234	0.158
Zn	µg/L		2.001	-	1.787	-		1.372	0.686	8.772	0.432	7.831	1.123	0.301	3.386	3.562	1.354
Co	µg/L		0.373	-	0.558	-	0.204	0.547	0.417	0.53	0.235	0.332	0.261	0.233	0.508	0.397	0.402

Table 8 Surface Water Sampling Results March 1998 (Round 8) (continued)

Analysis		Detection Limits	Watercourse Sampling Points														
			28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Inorganics		**mg/L**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**
Na^+	mg/L		2.1	-	-	-	-	2.3	-	-	-	1.8	1.2	7.9	-	-	-
K^+	mg/L		0.8	-	-	-	-	1.2	-	-	-	0.8	0.6	1.4	-	-	-
Ca^{2+}	mg/L		14.1	-	-	-	-	22.7	-	-	-	25.7	13.6	23.4	-	-	-
Mg^{2+}	mg/L		19.3	-	-	-	-	33.1	-	-	-	26.2	12.8	33.4	-	-	-
NH_4^+	mg/L		0.31	-	-	-	-	0.39	-	-	-	0.4	0.41	0.32	-	-	-
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	-	0.25	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L		12	-	-	-	-	22.5	-	-	-	13.5	30	4.5	-	-	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		103.7	-	-	-	-	207.4	-	-	-	189.1	85.4	262.3	-	-	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		17.6	-	-	-	-	21.76	-	-	-	19.13	17.32	27.87	-	-	-
Metals		**µg/L**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**
Mn	µg/L		-	-	-	-	-	0.01	-	-	-	0.18	0.06	0.05	-	-	-
Fe (III)	mg/L		-	-	-	-	-	0.01	-	-	-	0.18	0.06	0.05	-	-	-
Fe Total	mg/L		0.01	-	-	-	-	0.01	-	-	-	0.01	0.01	0.01	-	-	-
Al	mg/L		26.008	-	-	-	-	30.525	-	-	-	28.581	29.709	374.467	-	-	-
As	µg/L		1.252	-	-	-	-	1.169	-	-	-	1.414	1.049	0.975	-	-	-
Cd	µg/L		0.024	-	-	-	-	0.039	-	-	-	0.064	0.051	0.052	-	-	-
Ni	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		0.197	-	-	-	-	0.676	-	-	-	2.525	1.254	-	-	-	-
Cr	µg/L		1.348	-	-	-	-	1.609	-	-	-	1.61	1.164	1.224	-	-	-
Hg	µg/L		0.109	-	-	-	-	0.109	-	-	-	0.16	0.112	0.116	-	-	-
Zn	µg/L		1.081	-	-	-	-	1.471	-	-	-	49.679	0.495	2.165	-	-	-
Co	µg/L		0.297	-	-	-	-	0.509	-	-	-	0.598	0.248	0.411	-	-	-

Table 8 Surface Water Sampling Results March 1998 (Round 8) (continued)

Analysis		Detection Limits	Watercourse Sampling Points								Trip Blanks				
			43	44	45	46	47	48	49	50	51	52	53	54	55
Inorganics		**mg/L**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**
Na^+	mg/L		-	-	-	-	-	-	-	2.6	-	-	-	-	-
K^+	mg/L		-	-	-	-	-	-	-	2.8	-	-	-	-	-
Ca^{2+}	mg/L		-	-	-	-	-	-	-	49.3	-	-	-	-	-
Mg^{2+}	mg/L		-	-	-	-	-	-	-	34.1	-	-	-	-	-
NH_4^+	mg/L		-	-	-	-	-	-	-	0.33	1.2	0.45	0.61	1.79	2.88
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		-	-	-	-	-	-	-	10.25	-	-	-	-	-
SO_4^{2-}	mg/L		-	-	-	-	-	-	-	34.5	-	-	-	-	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		-	-	-	-	-	-	-	262.3	-	-	-	-	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		-	-	-	-	-	-	-	15.15	0.36	0.17	0.18	0.18	0.18
Metals		**µg/L**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**
Mn	µg/L		-	-	-	-	-	-	-	0.02	-	-	0.04	-	-
Fe (III)	mg/L		-	-	-	-	-	-	-	0.02	-	-	0.04	-	-
Fe Total	mg/L		-	-	-	-	-	-	-	0.01	0.01	0.01	0.01	0.01	0.01
Al	mg/L		-	-	-	-	-	-	-	15.744	0.645	1.706	4.628	3.408	2.096
As	µg/L		-	-	-	-	-	-	-	1.048	0.899	0.806	0.822	0.85	0.82
Cd	µg/L		-	-	-	-	-	-	-	0.083	0.176	0.138	0.103	0.029	0.068
Ni	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		-	-	-	-	-	-	-	-	5.699	6.499	5.95	3.994	4.862
Cu	µg/L		-	-	-	-	-	-	-	-	3.586	3.818	1.701	2.966	1.293
Cr	µg/L		-	-	-	-	-	-	-	1.08	0.031	0.122	0.112	0.017	0.078
Hg	µg/L		-	-	-	-	-	-	-	0.118	1.283	0.925	0.759	0.683	0.524
Zn	µg/L		-	-	-	-	-	-	-	5.995	6.499	12.285	6.587	15.322	8.277
Co	µg/L		-	-	-	-	-	-	-	0.368	0.079	0.01	-	0.022	0.006

Table 8 Surface Water Sampling Results March 1998 (Round 8) (continued)

Analysis		Detection Limits	QA Samples														
			56	57	58	59	60	61	62	63	64	65	66	67	68	69	70
Inorganics		**mg/L**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**
Na^+	mg/L		2.2	1.1	0.4	2.3	3.2	-	-	-	-	-	-	-	-	-	-
K^+	mg/L		0.7	1.6	0.5	0.3	2.7	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L		16.8	47.9	17.7	30.5	14.2	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L		19.1	45.1	18.9	14.4	2.5	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L		0.35	14.41	2.16	0.36	0.38	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		84.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		0.8	0.5	0.6	-	7.16	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L		9	3	7.5	7.5	0.01	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		115.9	347.7	103.7	170.8	36.6	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		17.42	17.24	13.79	18.74	17.77	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**
Mn	µg/L		0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe (III)	mg/L		0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		0.0.1	0.1	0.1	0.1	0.01	-	-	-	-	-	-	-	-	-	-
Al	mg/L		22.527	2.729	11.338	21.033	8.756	-	-	-	-	-	-	-	-	-	-
As	µg/L		1.318	1.193	0.928	1.348	0.991	-	-	-	-	-	-	-	-	-	-
Cd	µg/L		0.101	0.199	0.096	0.102	0.061	-	-	-	-	-	-	-	-	-	-
Ni	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		-	-	0.002	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		0.602	54.814	9.407	1.963	0.445	-	-	-	-	-	-	-	-	-	-
Cr	µg/L		2.01	2.072	2.56	1.018	2.346	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		0.456	0.314	0.258	0.208	0.44	-	-	-	-	-	-	-	-	-	-
Zn	µg/L		1.232	8.696	25.562	36.171	22.894	-	-	-	-	-	-	-	-	-	-
Co	µg/L		0.383	0.354	0.415	0.442	0.583	-	-	-	-	-	-	-	-	-	-

Table 8 Surface Water Sampling Results March 1998 (Round 8) (continued)

Analysis		Detection Limits	Fungurume Wells										Tenke Wells		
			101	102	103	104	105	106	107	108	109	110	111	112	113
Inorganics		**mg/L**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**	**8A**
Na^+	mg/L		2.5	5.8	3.3	2.3	3.5	2.7	13	51.6	18.9	-	1	8.2	-
K^+	mg/L		3.1	3	2.2	0.4	0.4	1.8	3.3	20.5	2.5	-	0.6	7.5	-
Ca^{2+}	mg/L		14.2	56.4	48.4	41.8	32.4	6.2	0.5	16	19.2	-	12.5	2	-
Mg^{2+}	mg/L		8	38	24	32.9	26.4	14.1	4.8	34.6	21	-	10.7	5.7	-
NH_4^+	mg/L		0.72	0.36	12.96	4.32	0.35	0.36	0.38	0.41	0.31	-	0.34	0.38	-
NO_2^-	mg/L		-	-	-	2.23	0.75	0.51	0.58	1.79	0.81	-	-	-	-
NO_3^-	mg/L		1.24	1.24	0.43	51.23	55.8	42.25	75.68	236.93	88.08	-	-	-	-
Cl^-	mg/L		6.96	14.52	9.55	3.48	11.04	5.17	10.05	92.81		-	-	8.16	-
SO_4^{2-}	mg/L		0.01	42	31.5	24	18	6	3	6	13.5	-	3	3	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		42.6	237.9	305	231.8	152.5	54.9	6.1	12.2	36.6	-	121.4	42.7	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		22.85	16.33	15.01	14.72	23.33	22.18	19.26	20.72	17.61	-	16.04	6.87	-
Metals		**µg/L**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**	**8B**
Mn	µg/L		-	-	-	0.03	-	-	-	-	-	-	-	-	-
Fe (III)	mg/L		-	-	-	0.03	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		0.01	0.1	0.01	0.01	0.01	0.1	0.1	0.18	0.01	-	0.1	0.1	-
Al	mg/L		9.464	8.592	3.473	5.104	6.52	8.17	88.7	407.748	26.501	-	5.71	111.504	-
As	µg/L		1.007	1.113	1.088	0.997	1.121	0.983	1.094	2.816	1.841	-	1.217	1.422	-
Cd	µg/L		0.031	0.126	0.16	0.175	0.192	0.067	0.282	0.351	0.232	-	0.247	0.246	-
Ni	µg/L		-	-	-	-	-	-	9.441	76.63	-	-	-	-	-
Pb	µg/L		0.192	0.101	-	-	-		1.63	0.186	-	-	-	0.046	-
Cu	µg/L		4.44	0.219	-	0.062	-	0.18	12.891	23.831	1.202	-	0.142	0.97	-
Cr	µg/L		2.443	2.197	1.237	1.474	1.443	1.4	1.301	1.13	1.19	-	2.204	2.035	-
Hg	µg/L		0.453	0.287	0.205	0.38	0.2	0.193	0.202	0.386	0.268	-	0.054	0.168	-
Zn	µg/L		115.54	28.399	6.914	23.103	10.592	7.082	109.53	96.543	11.574	-	33.274	11.894	-
Co	µg/L		0.664	0.605	0.394	0.38	0.386	0.567	97.961	156.32	5	-	0.452	1.268	-

Table 9 Surface Water Sampling Results April 1998 (Round 9)

Analysis		Detection Limits	Water Supply Infrastructure						Watercourse Sampling Points								
			Borehole 1	Reservoirs		Distribution System			4	5	6	7	8	9	10	11	12
				2.1	2.2	3.1	3.2	3.3									
Inorganics		**mg/L**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**
Na^+	mg/L		-	1.7	-	-	-	-	93	5.4	1.1	1.4	1.1	5	0.6	4.4	8
K^+	mg/L		-	1.8	-	-	-	-	3.1	0.9	0.2	2.7	1.1	1.1	0.2	0.1	-
Ca^{2+}	mg/L		-	59.2	-	-	-	-	45.8	27.2	21	44	59.8	32.9	25	17	26.4
Mg^{2+}	mg/L		-	59.1	-	-	-	-	24.5	28.6	14.8	45.9	49.7	38.8	17.4	21.9	15.7
NH_4^+	mg/L		-	0.36	-	-	-	-	1.08	0.36	0.37	0.33	0.4	0.36	0.36	0.37	1.8
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		-	1.29	-	-	-	-	162.44	2.08	1.78	4.75	1.19	1.39	0.99	0.99	1.68
SO_4^{2-}	mg/L		-	27	-	-	-	-	24	9	-	6	36	15	-	18	12
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		-	451.4	-	-	-	-	189.1	207.4	128.1	366	372.1	262.3	81.2	314.2	82.4
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		-	21.39	-	-	-	-	21.01	18.05	20.02	19.57	21.35	19.23	20.17	15.42	19.42
Metals		**µg/L**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**
Mn	µg/L		-	1.976	-	-	-	-	148.9	40.554	54.899	41.527	4.712	10.086	10.163	9.729	17.063
Fe (III)	mg/L		-	0.014	-	-	-	-	-	-	-	-	0.3	-	-	-	0.014
Fe Total	mg/L		-	0.014	-	-	-	-	-	-	-	-	0.3	-	-	-	0.014
Al	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L		-	1.413	-	-	-	-	3.201	1.588	1.666	0.886	0.719	0.651	0.984	0.432	0.898
Cd	µg/L		-	0.239	-	-	-	-	0.049	-	0.014	0.009	0.072	0.036	0.023	-	0.014
Ni	µg/L		-	2.2	-	-	-	-	3.018	1.919	1.584	2.767	3.61	3.119	2.377	1.765	2.017
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		-	8.625	-	-	-	-	2.613	3.694	1.72	1.338	4.207	2.361	1.761	6.955	3.062
Cr	µg/L		-	2.316	-	-	-	-	2.469	1.95	1.994	2.048	3.002	2.251	2.033	2.002	1.037
Hg	µg/L		-	0.408	-	-	-	-	1.134	0.075	0.067	-	-	-	-	-	-
Zn	µg/L		-	11.638	-	-	-	-	7.447	10.612	-	1.924	4.975	0.861	-	-	14.784
Co	µg/L		-	0.591	-	-	-	-	0.827	0.83	0.436	0.826	0.554	0.424	0.329	0.323	0.384

Table 9 Surface Water Sampling Results April 1998 (Round 9) (continued)

Analysis		Detection Limits	Watercourse Sampling Points														
			13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Inorganics		**mg/L**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**
Na^+	mg/L		3.2	3.2	-	2.5	-	2	9.3	5	-	1.5	1.1	0.7	57	-	3.2
K^+	mg/L		1.4	0.4	-	0.8	-		1.3	1.6	-	-	0.9	0.8	0.4	-	2
Ca^{2+}	mg/L		25.7	29.5	-	27.8	-	7.2	35.6	22.1	-	15.5	46.2	10.1	9.9	-	36.1
Mg^{2+}	mg/L		15.1	31	-	25.7	-	8.9	39.6	17.3	-	11.7	43.2	9.2	9.1	-	18.2
NH_4^+	mg/L		0.32	0.33	-	0.36	-	0.35	0.35	0.38	-	14	2.16	0.35	0.38	-	0.36
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		1.39	1.39	-	1.29	-	-	-	2.57	-	3.17		1.88	2.28	-	100.08
SO_4^{2-}	mg/L		3	27	-	15	-	9	15	15	-	12	9	15	9	-	30
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		164.7	231.8	-	201.3	-	61	311.1	170.8	-	103.7	372.1	54.9	54.9	-	158.6
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		19.38	20.37	-	18.27	-	21.93	25.31	21.09	-	23.3	19.92	14.4	14.55	-	19.68
Metals		**µg/L**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**
Mn	µg/L		36.764	23.873	-	25.607	-	192.37	12.384	59.102	-	11.78	0.468	21.3	45.178	-	105.42
Fe (III)	mg/L		-	-	-	-	-	0.308	-	-	-	-	-	0.043	-	-	-
Fe Total	mg/L		-	-	-	-	-	0.308	-	-	-	-	-	0.043	-	-	-
Al	mg/L		-	-	-	-	-	S	-	-	-	-	-	-	-	-	-
As	µg/L		1.003	0.704	-	0.745	-	0.483	0.639	1.272	-	0.748	0.594	0.483	0.412	-	2.783
Cd	µg/L		0.017	0.009	-	0.034	-	0.027	0.023	0.035	-	0.093	0.026	-	-	-	0.042
Ni	µg/L		3.375	2.576	-	1.928	-	1.496	3.414	2.511	-	1.842	3.195	1.735	1.209	-	2.591
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		0.977	1.405	-	3.042	-	0.97	1.685	1.418	-	2.329	54.344	1.475	0.501	-	1.521
Cr	µg/L		1.365	2.226	-	2.412	-	2.222	2.699	1.518	-	2.536	2.479	2.532	2.101	-	2.233
Hg	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.006
Zn	µg/L		-	2.236	-	2.955	-	-	0.077	-	-	55.618	4.905	0.408	-	-	2.367
Co	µg/L		0.439	0.496	-	0.592	-	0.744	0.601	0.688	-	0.566	0.397	0.313	0.316	-	0.608

Table 9 Surface Water Sampling Results April 1998 (Round 9) (continued)

Analysis		Detection Limits	Watercourse Sampling Points														
			28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Inorganics		**mg/L**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**
Na^+	mg/L		-	3	-	-	-	-	1.6	-	-	-	-	9.2	5.2	-	-
K^+	mg/L		-	0.6	-	-	-	-	0.9	-	-	-	-	-	0.6	-	-
Ca^{2+}	mg/L		-	32.4	-	-	-	-	22.3	-	-	-	-	19.2	20	-	-
Mg^{2+}	mg/L		-	34.5	-	-	-	-	25.3	-	-	-	-	15	31.7	-	-
NH_4^+	mg/L		-	18.01	-	-	-	-	0.36	-	-	-	-	0.35	0.33	-	-
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		-	1.39	-	-	-	-	1.19	-	-	-	-	-	1.19	-	-
SO_4^{2-}	mg/L		-	24	-	-	-	-	15	-	-	-	-	9	12	-	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		-	250.1	-	-	-	-	276.9	-	-	-	-	122	414.8	-	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		-	20.51	-	-	-	-	21.93	-	-	-	-	20.51	34.1	-	-
Metals		**µg/L**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**
Mn	µg/L		-	24.47	-	-	-	-	13.463	-	-	-	-	23.008	333.89	-	-
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	0.004	-	-	-
Fe Total	mg/L		-	-	-	-	-	-	-	-	-	-	-	0.004	-	-	-
Al	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L		-	0.865	-	-	-	-	0.591	-	-	-	-	0.511	0.484	-	-
Cd	µg/L		-	0.075	-	-	-	-	0.064	-	-	-	-	-	0.05	-	-
Ni	µg/L		-	3.546	-	-	-	-	2.562	-	-	-	-	2.41	3.643	-	-
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		-	5.95	-	-	-	-	3.847	-	-	-	-	2.25	0.317	-	-
Cr	µg/L		-	2.489	-	-	-	-	2.422	-	-	-	-	2.825	4.154	-	-
Hg	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L		-	135.9	-	-	-	-	18.49	-	-	-	-	1.855	1.477	-	-
Co	µg/L		-	0.979	-	-	-	-	0.545	-	-	-	-	0.351	0.53	-	-

Table 9 Surface Water Sampling Results April 1998 (Round 9) (continued)

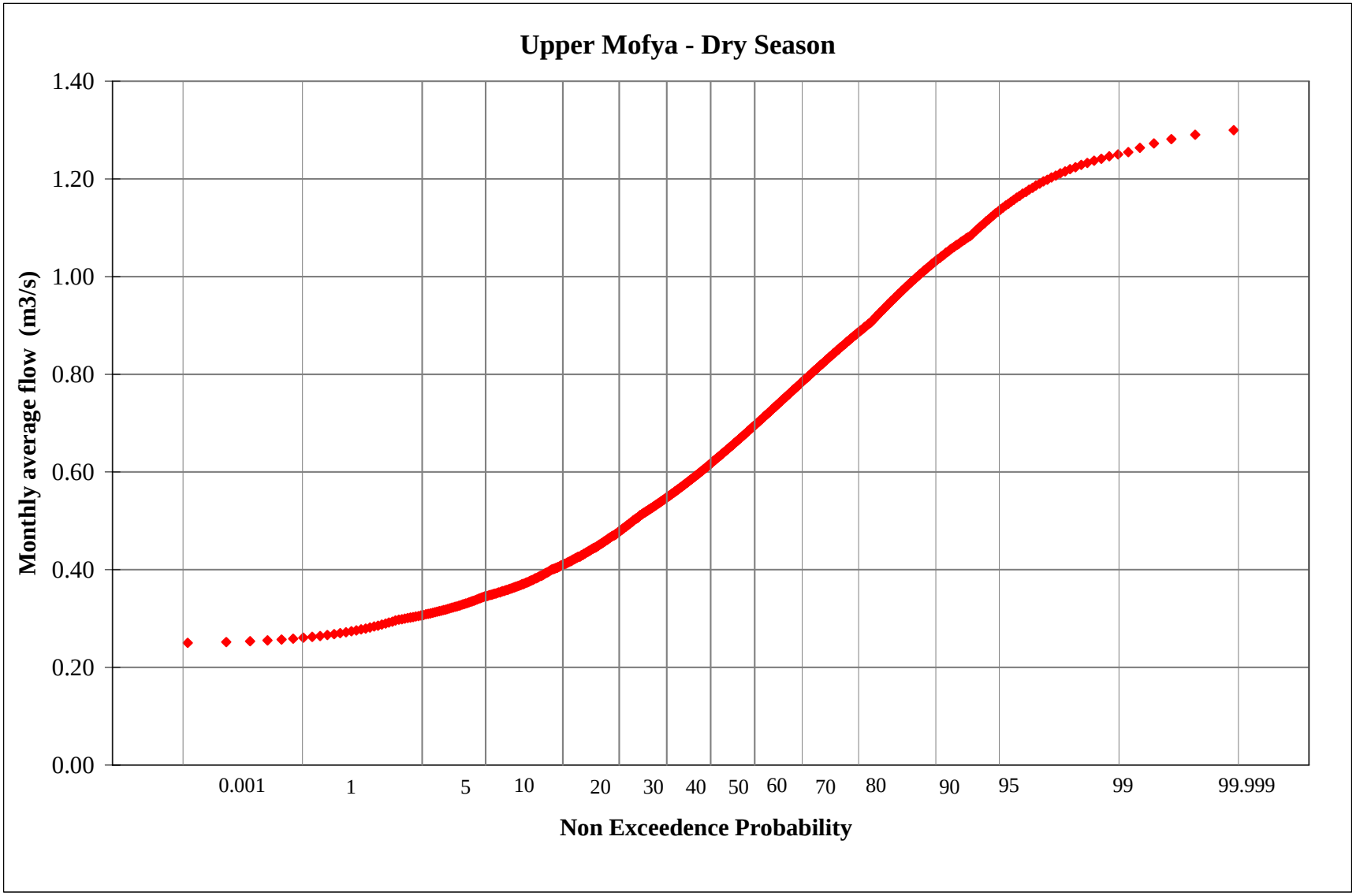
Analysis		Detection Limits	Watercourse Sampling Points								Trip Blanks				
			43	44	45	46	47	48	49	50	51	52	53	54	55
Inorganics		**mg/L**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**
Na^+	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
K^+	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L		-	-	-	-	-	-	-	16.4	-	-	-	-	-
Mg^{2+}	mg/L		-	-	-	-	-	-	-	11.7	-	-	-	-	-
NH_4^+	mg/L		-	-	-	-	-	-	-	0.038	0.38	0.37	0.4	0.38	0.36
NO_2^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		-	-	-	-	-	-	-	2.77	-	-	-	-	-
SO_4^{2-}	mg/L		-	-	-	-	-	-	-	9	-	-	-	-	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		-	-	-	-	-	-	-	103.7	-	-	-	-	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		-	-	-	-	-	-	-	24.43	1.75	1.28	1.26	1.26	1.26
Metals		**µg/L**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**
Mn	µg/L		-	-	-	-	-	-	-	19.113	1.527	2.052	0.833	1.619	6.564
Fe (III)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Al	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L		-	-	-	-	-	-	-	0.784	0.286	0.258	0.257	0.428	0.295
Cd	µg/L		-	-	-	-	-	-	-	0.103	0.036	0.077	0.026	0.074	0.027
Ni	µg/L		-	-	-	-	-	-	-	2.09	-	-	-	0.163	0.637
Pb	µg/L		-	-	-	-	-	-	-	-	1.996	1.24	0.687	1.495	-
Cu	µg/L		-	-	-	-	-	-	-	3.607	3.754	3.288	2.783	6.207	5.972
Cr	µg/L		-	-	-	-	-	-	-	2073	0.275	0.154	0.427	0.332	0.257
Hg	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	0.653
Zn	µg/L		-	-	-	-	-	-	-	78.939	6.407	6.233	5.037	17.13	10.063
Co	µg/L		-	-	-	-	-	-	-	0.438	0.015	0.012	0.01	0.131	0.922

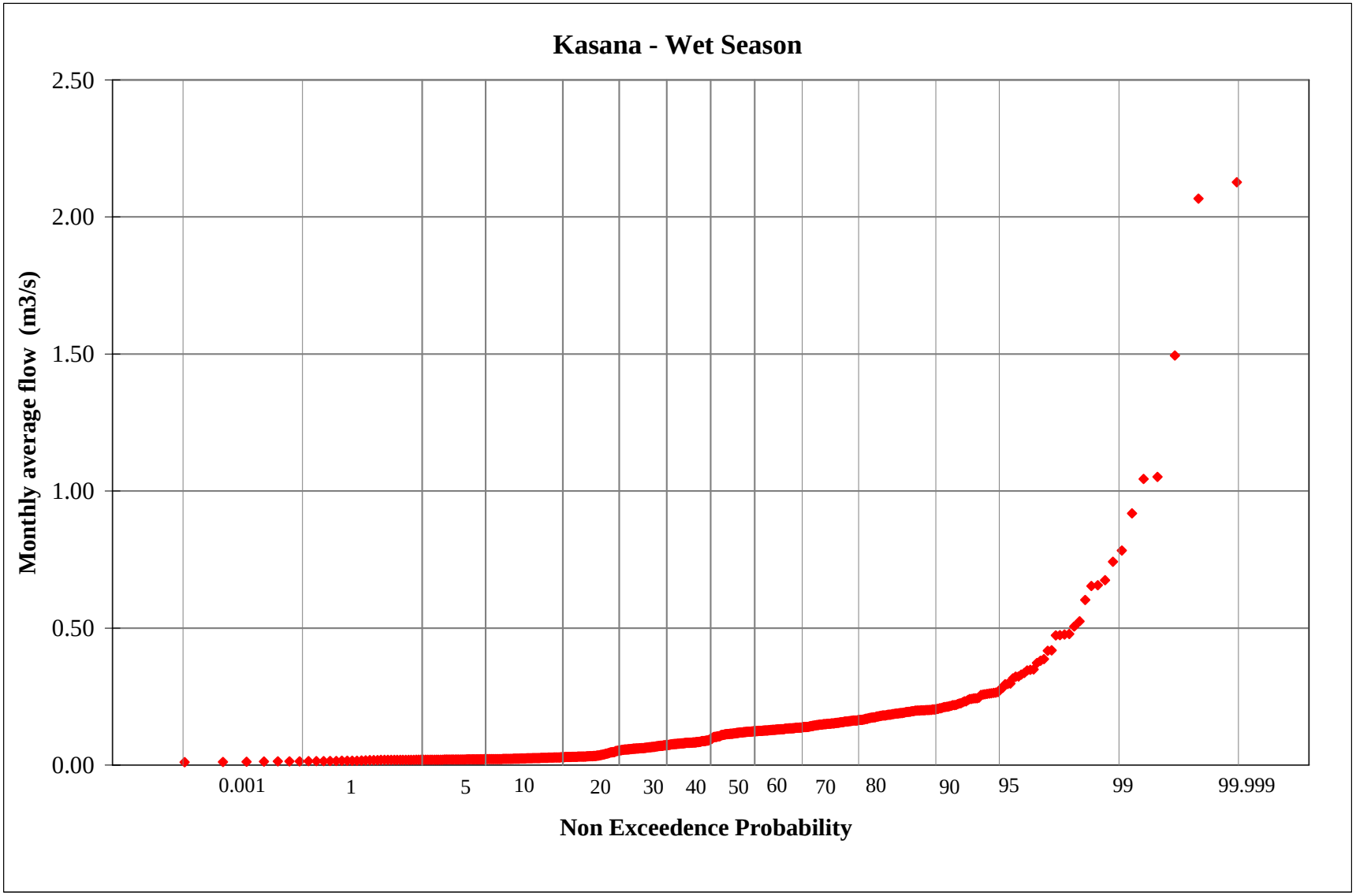
Table 9 Surface Water Sampling Results April 1998 (Round 9) (continued)

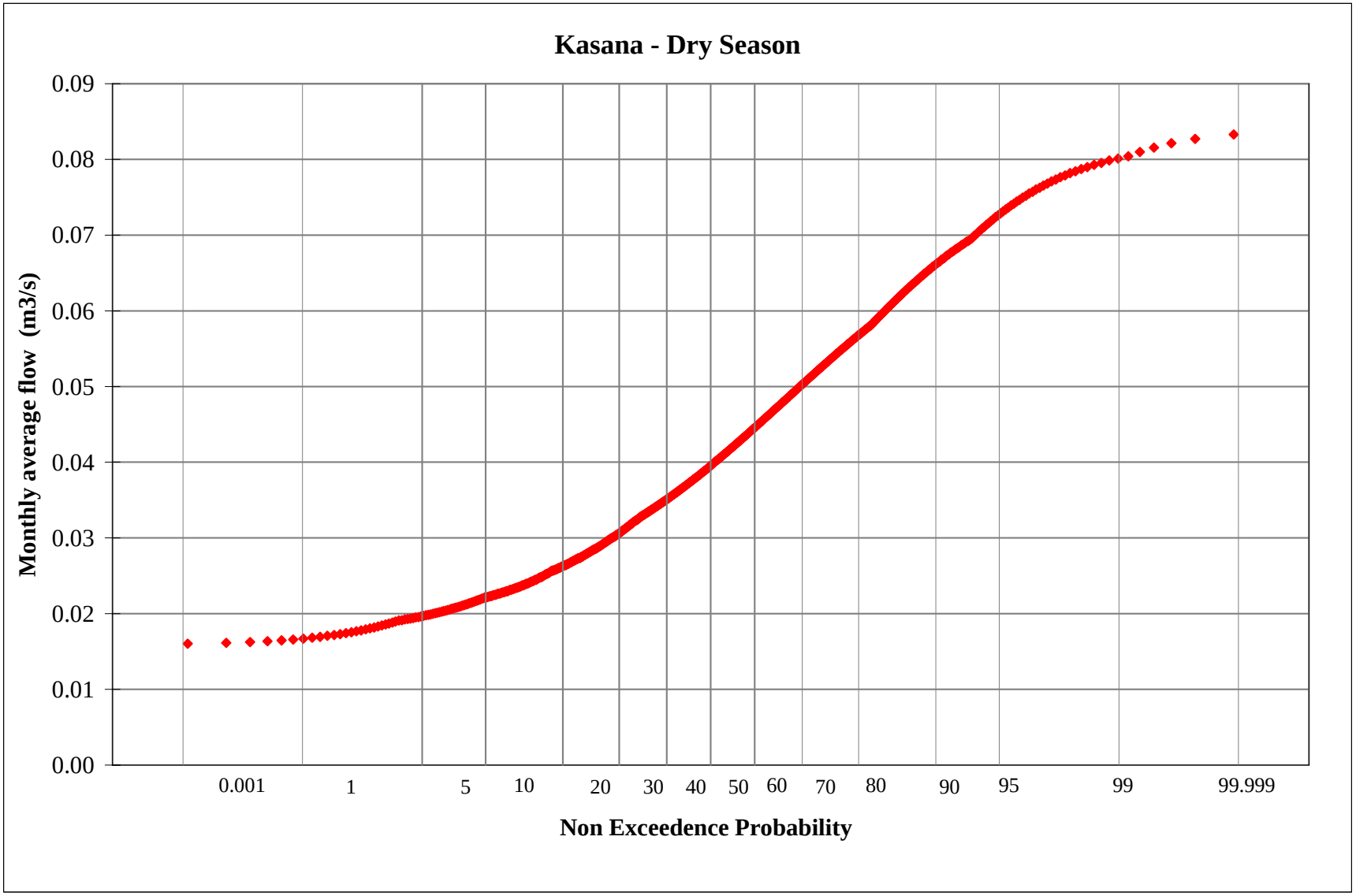
Analysis		Detection Limits	QA Samples														
			56	57	58	59	60	61	62	63	64	65	66	67	68	69	70
Inorganics		**mg/L**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**
Na^+	mg/L		1.6	4.9	2.8	4.5	6.7	-	-	-	-	-	-	-	-	-	-
K^+	mg/L		1	0.2	0.6	0.1	2.1	-	-	-	-	-	-	-	-	-	-
Ca^{2+}	mg/L		30.8	20.3	35	22.2	52.8	-	-	-	-	-	-	-	-	-	-
Mg^{2+}	mg/L		39.3	14.6	34.7	15.6	36.4	-	-	-	-	-	-	-	-	-	-
NH_4^+	mg/L		0.36	0.32	0.35	0.33	0.37	-	-	-	-	-	-	-	-	-	-
NO_2^-	mg/L		-	-	-	-	2.15	-	-	-	-	-	-	-	-	-	-
NO_3^-	mg/L		-	-	-	-	65.165	-	-	-	-	-	-	-	-	-	-
Cl^-	mg/L		0.8	0.89	0.99	-	14.16	-	-	-	-	-	-	-	-	-	-
SO_4^{2-}	mg/L		16.5	15	24	27	39	-	-	-	-	-	-	-	-	-	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		164.7	128.1	250.1	140.3	262.3	-	-	-	-	-	-	-	-	-	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		25.05	19.92	20.41	19.38	19.53	-	-	-	-	-	-	-	-	-	-
Metals		**µg/L**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**
Mn	µg/L		9.197	56.911	21.629	18.692	8.13	-	-	-	-	-	-	-	-	-	-
Fe (III)	mg/L		-	-	-	0.005	0.022	-	-	-	-	-	-	-	-	-	-
Fe Total	mg/L		-	-	-	0.005	0.022	-	-	-	-	-	-	-	-	-	-
Al	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
As	µg/L		0.63	1.221	0.679	1.021	0.542	-	-	-	-	-	-	-	-	-	-
Cd	µg/L		0.083	0.058	0.029	0.18	0.061	-	-	-	-	-	-	-	-	-	-
Ni	µg/L		3.227	2.731	2.487	2.452	5.196	-	-	-	-	-	-	-	-	-	-
Pb	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cu	µg/L		1.761	2.364	3.635	5.216	1.739	-	-	-	-	-	-	-	-	-	-
Cr	µg/L		1.995	2.158	1.954	2.135	3.266	-	-	-	-	-	-	-	-	-	-
Hg	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L		0.95	-	82.993	88.492	25.741	-	-	-	-	-	-	-	-	-	-
Co	µg/L		0.66	0.483	0.825	0.747	0.908	-	-	-	-	-	-	-	-	-	-

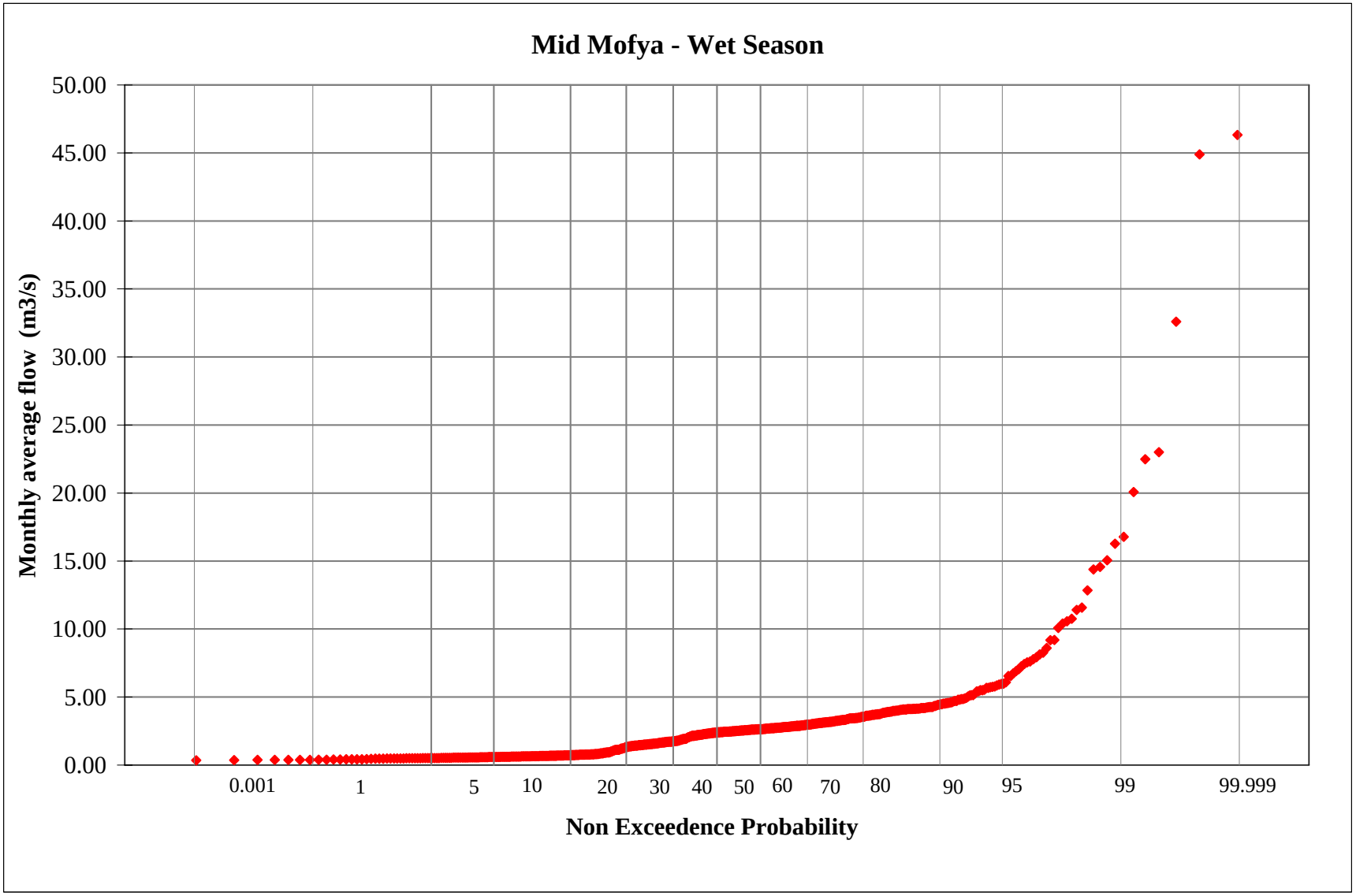
Table 9 Surface Water Sampling Results April 1998 (Round 9) (continued)

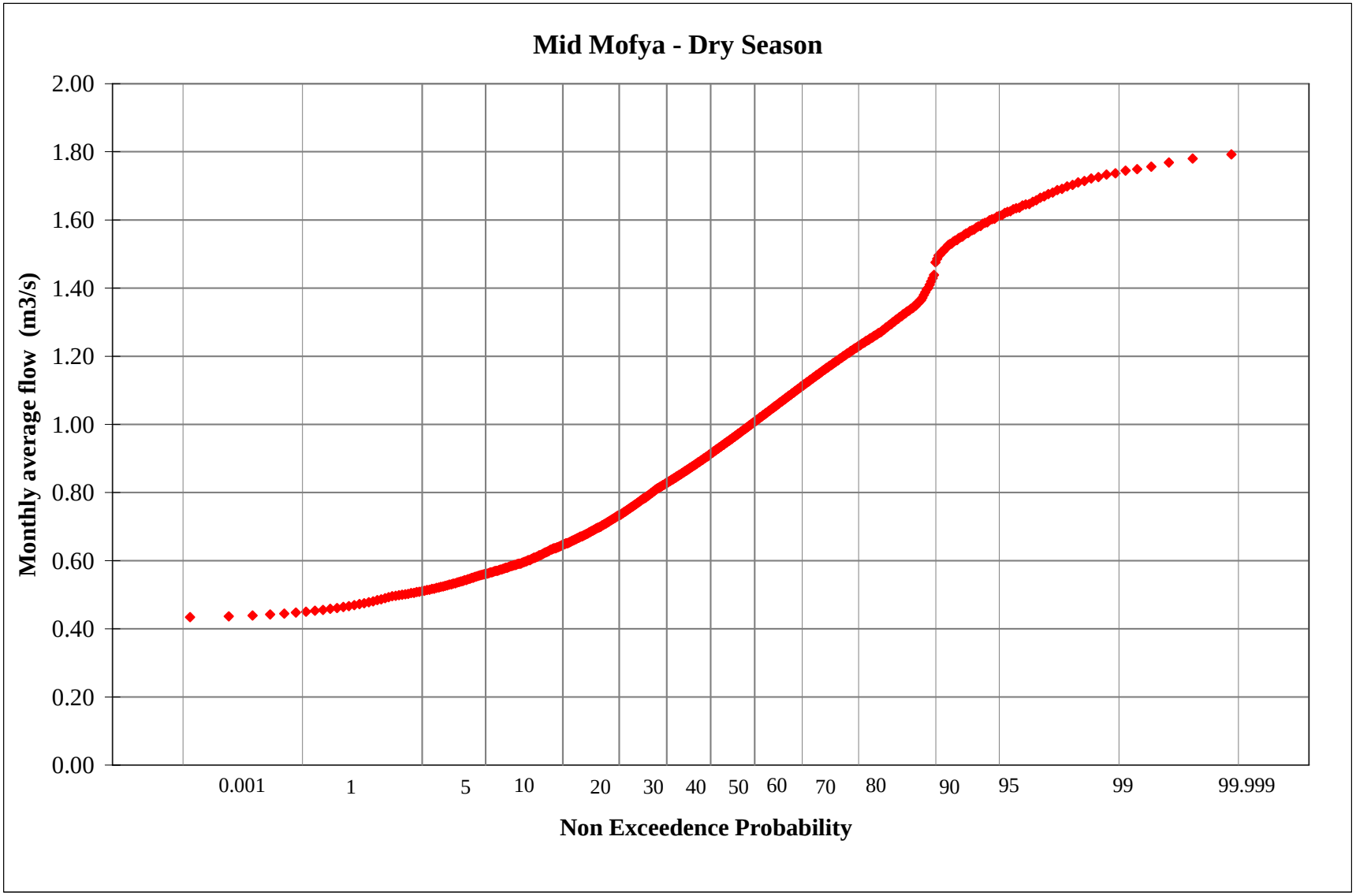
Analysis		Detection Limits	Fungurume Wells										Tenke Wells		
			101	102	103	104	105	106	107	108	109	110	111	112	113
Inorganics		**mg/L**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**	**9A**
Na^+	mg/L		3.2	6.7	3.6	2.6	4.5	3.3	14.8	52	19.1	-	1.6	8.4	-
K^+	mg/L		2.2	2.2	3.3	0.5	1	2.4	3.7	21.3	3.3	-	1.1	8.9	-
Ca^{2+}	mg/L		12.7	52.7	50	39.1	33.9	5.4	1.3	12.9	23.7	-	16.4	2.3	-
Mg^{2+}	mg/L		7.3	36.5	36.4	30.7	25.8	12.3	4.8	35.8	25.1	-	12.9	6	-
NH_4^+	mg/L		0.35	0.34	8	0.38	0.35	0.4	0.33	0.32	0.34	-	0.36	0.39	-
NO_2^-	mg/L		-	3.66	2.7	-	1.63	-	-	-	-	-	-	-	-
NO_3^-	mg/L		41.133	64.912	29.654	1.946	46.1	25.461	66.924	335.082	81.814	-	-	-	-
Cl^-	mg/L		7.62	14.65	10.69	3.46	11.09	5.94	9.21	89.09	40.19	-	-	5.25	-
SO_4^{2-}	mg/L		6	87	30	30	21	15	37	10.5	27	-	12	15	-
PO_4^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	mg/L		42.7	250.1	274.5	228.1	164.7	54.9	6.1	6.1	37.8	-	91.5	42.7	-
CO_3^{2-}	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
SiO_2	mg/L		25.8	19.42	18.2	16.34	27.25	27.21	22.65	26.27	21.24	-	19.68	6.67	-
Metals		**µg/L**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**	**9B**
Mn	µg/L		2.635	7.986	0.63	2.734	6.03	4.652	86.726	375.16	33.254	-	2.008	126.63	-
Fe (III)	mg/L		0.061	0.019	-	0.04	0.101	0.008	0.094	0.016	-	-	0.167	-	-
Fe Total	mg/L		0.061	0.019	-	0.04	0.101	0.008	0.094	0.016	-	-	0.167	-	-
Al	mg/L		-	-	-	-	-	-	0.08	0.13	-	-	-	-	-
As	µg/L		0.438	0.599	0.53	0.423	0.521	0.503	0.529	2.554	1.278	-	0.753	1.023	-
Cd	µg/L		0.009	0.05	0.03	0.052	0.063	0.041	0.103	0.231	0.018	-	0.02	-	-
Ni	µg/L		3.477	3.576	3.923	3.501	2.935	1.944	26.593	129.32	10.009	-	3.142	2.029	-
Pb	µg/L		-	-	-	-	-	-	1.095	0.714	-	-	-	-	-
Cu	µg/L		0.787	1.092	0.816	0.787	1.021	0.242	14.345	39.302	2.523	-	1.077	2.356	-
Cr	µg/L		2.503	2.242	2.351	2.585	2.227	1.823	2.62	2.264	1.865	-	3.128	3.549	-
Hg	µg/L		-	-	-	-	-	-	-	-	-	-	-	-	-
Zn	µg/L		5.878	17.214	9.258	53.063	11.188	8.216	138.13	136.62	10.284	-	26.639	8.242	-
Co	µg/L		0.274	0.849	0.532	0.453	0.52	0.477	105.53	4 187.57	6.57	-	0.726	2.053	-

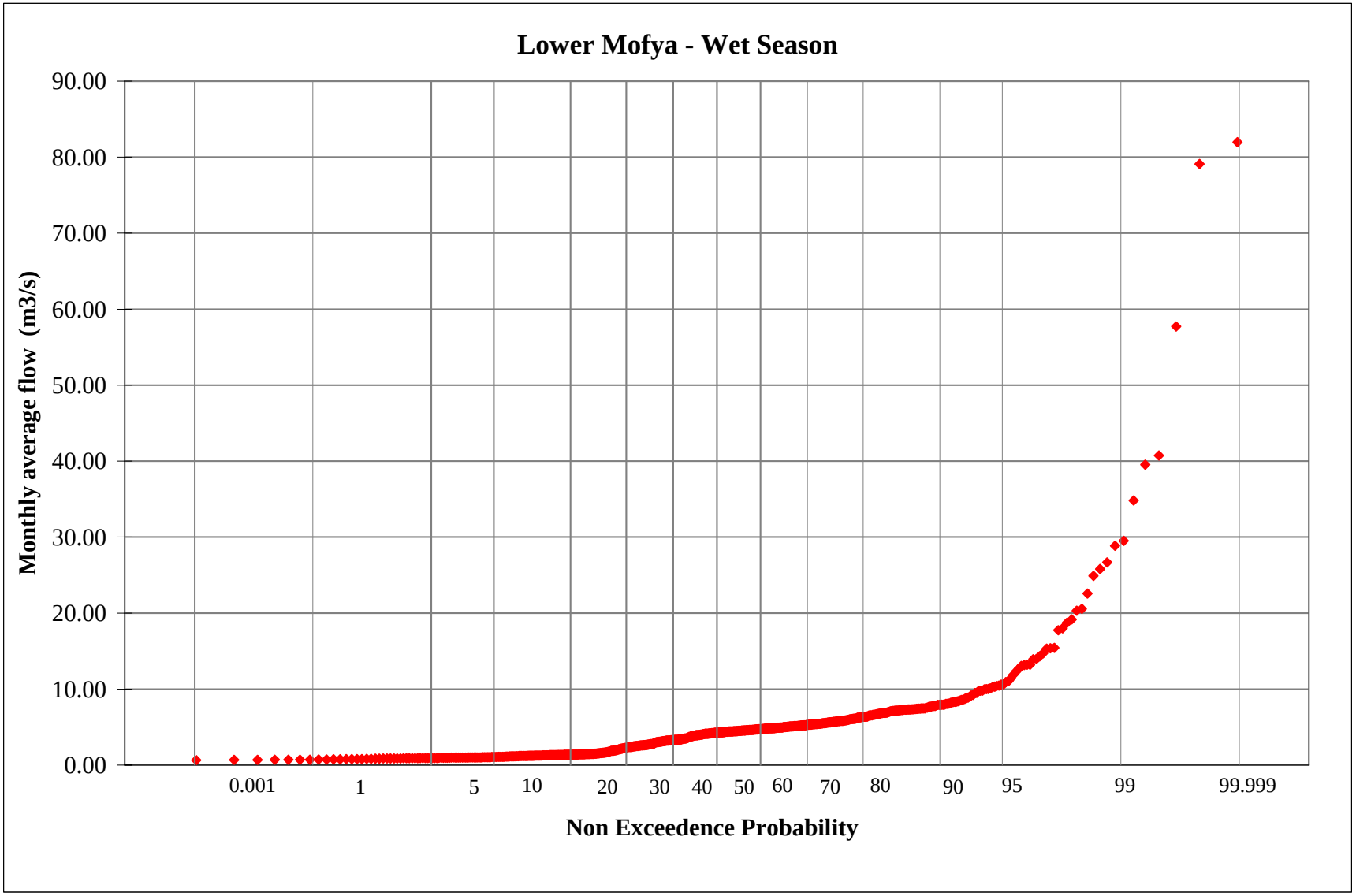

Upper Mofya - Dry Season
Monthly average flow (m3/s)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability

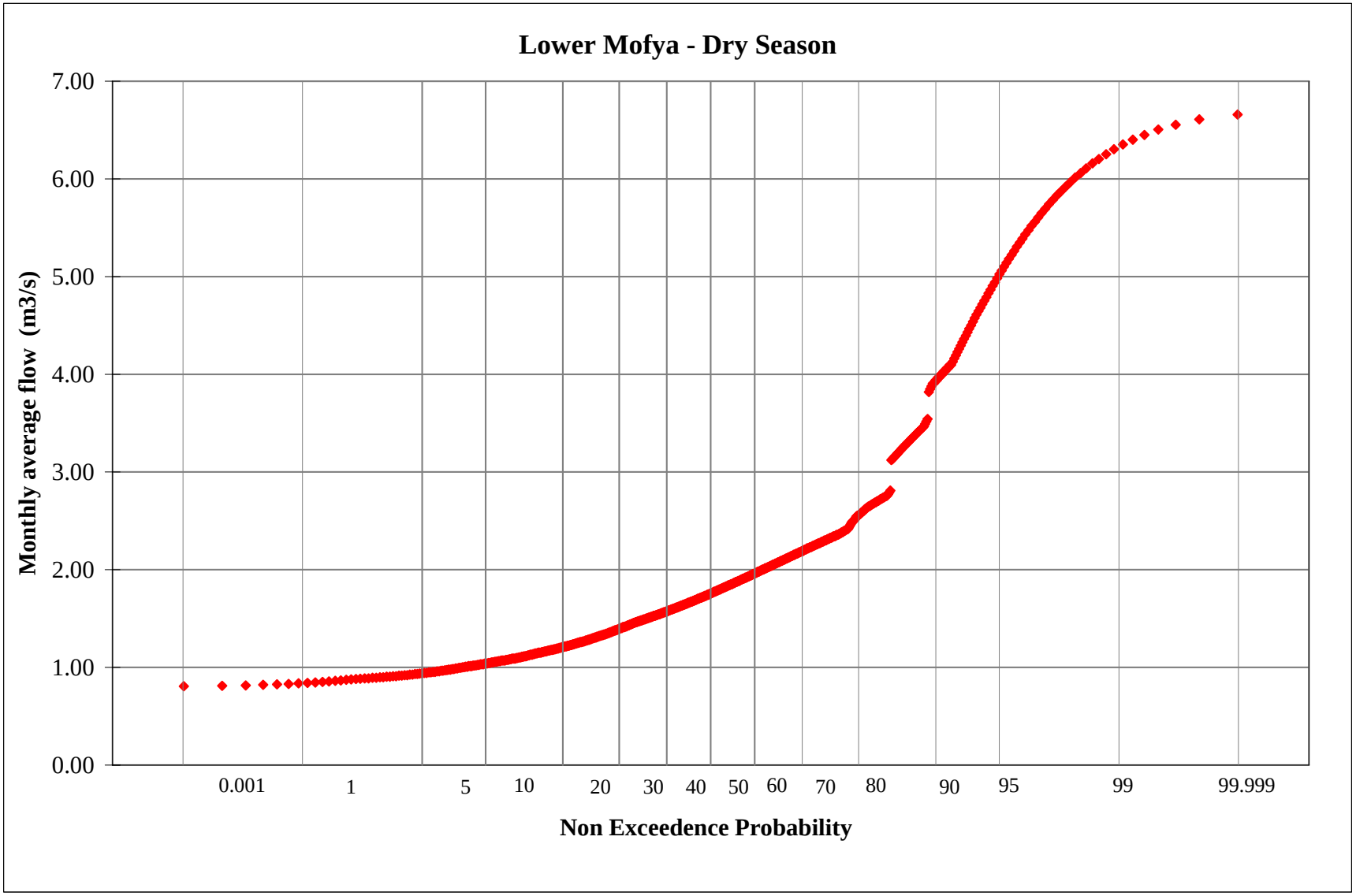

Kasana - Wet Season
Monthly average flow (m3/s)
2.50
2.00
1.50
1.00
0.50
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability


Kasana - Dry Season
Monthly average flow (m3/s)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability


Mid Mofya - Wet Season
Monthly average flow (m3/s)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability


Mid Mofya - Dry Season
Monthly average flow (m3/s)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability


Lower Mofya - Wet Season
Monthly average flow (m3/s)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability


Lower Mofya - Dry Season
Monthly average flow (m3/s)
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.001
1
5
10
20
30
40
50
60
70
80
90
95
99
99.999
Non Exceedence Probability

APPENDIX B2.13-I

DETAILED TRAFFIC SURVEY RESULTS

Table 1 Traffic Between Fungurume and the Kafwaya Cutoff Road, June 13, 2006

	Type of Vehicle												
Hour of the Day	**Personal Car**	**Taxi, Minibus**	**Passenger Bus**	**Single-axle (pick-up) Truck**	**Double Rear-axle Truck**	**Semi-trailer**	**Grader, Earth-Mover**	**Tanker Truck**	**Motorcycle**	**Bicycle**	**Pedestrian**	**Other**	**Total**
08-09	0	0	0	3	0	0	0	0	0	12	14	0	29
09-10	0	0	0	0	0	0	0	0	1	41	15	0	57
10-11	3	0	0	1	0	0	0	0	0	50	22	0	76
11-12	0	0	0	0	0	0	0	0	0	38	9	0	47
12-13	0	0	0	1	0	0	0	0	1	35	8	1	46
13-14	1	0	0	0	0	0	0	0	0	46	1	0	48
14-15	0	0	0	0	0	0	0	0	0	34	2	0	36
15-16	0	0	0	1	0	2	0	0	3	42	7	0	55
16-17	0	0	0	1	0	0	0	0	0	11	2	0	14
Total	**4**	**0**	**0**	**7**	**0**	**2**	**0**	**0**	**5**	**309**	**80**	**1**	**408**

Table 2 Traffic Between Fungurume and the Kafwaya Cutoff Road, June 14, 2006

	Type of Vehicle												
Hour of the Day	**Personal Car**	**Taxi, Minibus**	**Passenger Bus**	**Single-axle (pick-up) Truck**	**Double Rear-axle Truck**	**Semi-trailer**	**Grader, Earth-Mover**	**Tanker Truck**	**Motorcycle**	**Bicycle**	**Pedestrian**	**Other**	**Total**
08-09	0	1	0	2	0	0	0	0	0	3	10	0	16
09-10	0	0	0	2	0	0	0	0	0	5	7	0	14
10-11	0	0	2	0	0	0	0	0	0	5	10	0	17
11-12	0	0	1	2	2	0	0	0	0	5	18	0	28
12-13	0	0	1	0	0	0	0	0	0	5	5	1	12
13-14	2	0	0	1	0	0	0	0	0	7	6	2	18
14-15	0	0	0	1	0	0	0	0	0	4	11	1	17
15-16	0	0	0	0	0	0	0	0	0	6	15	0	21
16-17	0	0	0	0	0	0	0	0	0	1	2	1	4
Total	**2**	**1**	**4**	**8**	**2**	**0**	**0**	**0**	**0**	**41**	**84**	**5**	**147**

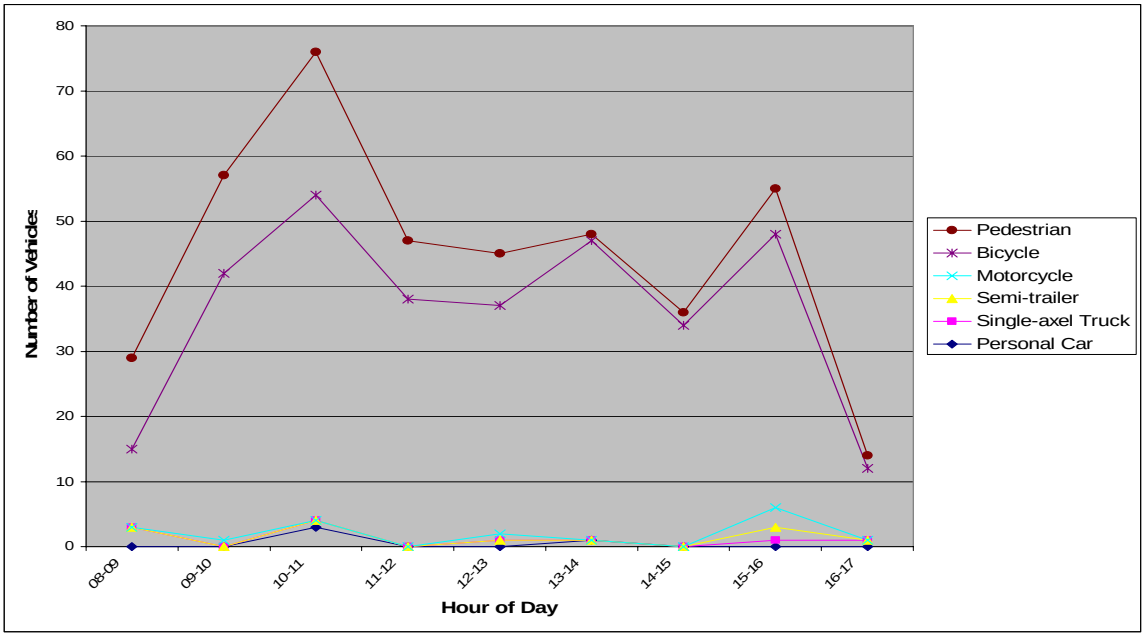
Table 3 Traffic Along the Mulumbu Access Road, June 13, 2006

	Type of Vehicle												
Hour of the Day	**Personal Car**	**Taxi, Minibus**	**Passenger Bus**	**Single-axle (pick-up) Truck**	**Double Rear-axle Truck**	**Semi-trailer**	**Grader, Earth-Mover**	**Tanker Truck**	**Motorcycle**	**Bicycle**	**Pedestrian**	**Other**	**Total**
08-09	0	0	0	3	0	0	0	0	1	0	13	10	27
09-10	0	0	0	0	0	0	0	0	0	0	18	10	28
10-11	3	0	0	1	0	0	0	0	0	0	52	2	58
11-12	0	0	0	0	0	0	0	0	0	0	39	8	47
12-13	0	0	0	1	0	0	0	0	1	0	34	6	42
13-14	1	0	0	0	0	0	0	0	0	0	46	1	48
14-15	0	0	0	0	0	0	0	0	0	0	34	2	36
15-16	0	0	0	1	0	2	0	0	2	1	47	6	59
16-17	0	0	0	1	0	0	0	0	0	0	15	2	18
Total	**4**	**0**	**0**	**7**	**0**	**2**	**0**	**0**	**4**	**1**	**298**	**47**	**363**

Table 4 Traffic Along the Mulumbu Access Road, June 16, 2006

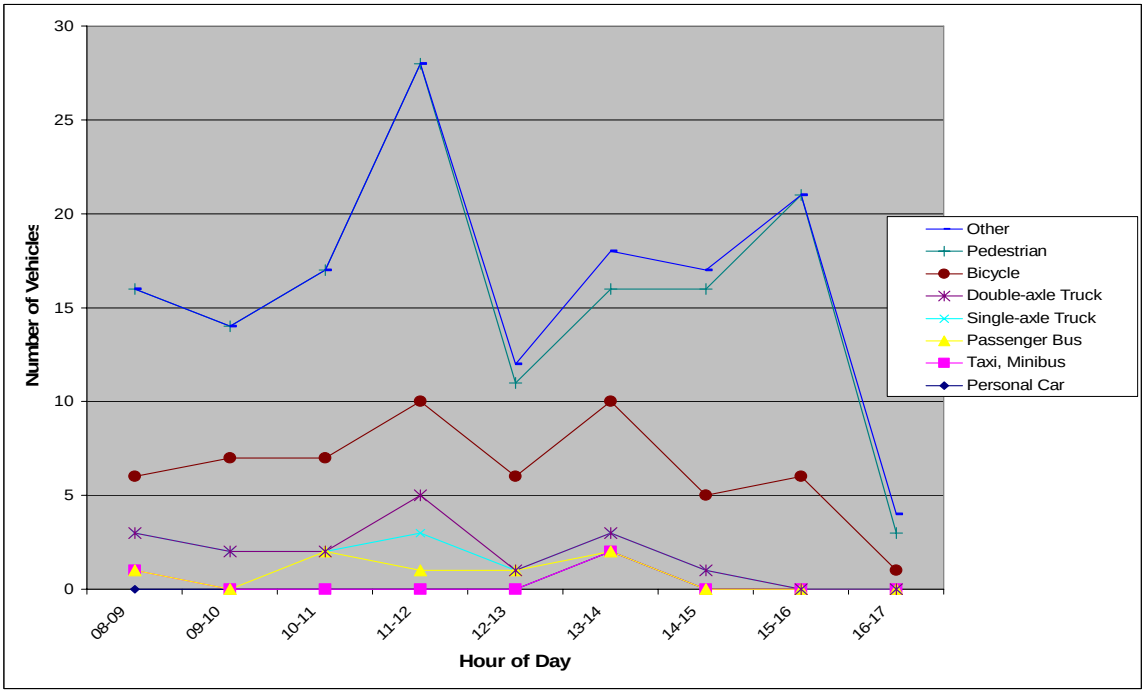
	Type of Vehicle												
Hour of the Day	**Personal Car**	**Taxi, Minibus**	**Passenger Bus**	**Single-axle (pick-up) Truck**	**Double Rear-axle Truck**	**Semi-trailer**	**Grader, Earth-Mover**	**Tanker Truck**	**Motorcycle**	**Bicycle**	**Pedestrian**	**Other**	**Total**
08-09	0	0	0	0	3	0	0	0	0	57	23	0	83
09-10	0	0	0	0	0	3	0	0	0	39	3	0	45
10-11	0	0	0	0	1	0	0	2	1	45	6	0	55
11-12	0	0	0	0	2	0	0	0	0	47	10	0	59
12-13	0	0	0	1	0	1	0	0	0	38	17	0	57
13-14	0	0	0	0	0	0	0	0	1	79	6	0	86
14-15	0	0	0	1	0	0	0	0	1	10	7	0	19
15-16	0	0	0	0	0	0	0	0	0	72	6	0	78
16-17	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**0**	**0**	**0**	**2**	**6**	**4**	**0**	**2**	**3**	**387**	**78**	**0**	**482**

Figure 1 **Vehicle Traffic Between Fungurume and the Kafwaya Cutoff Road June 13, 2006**



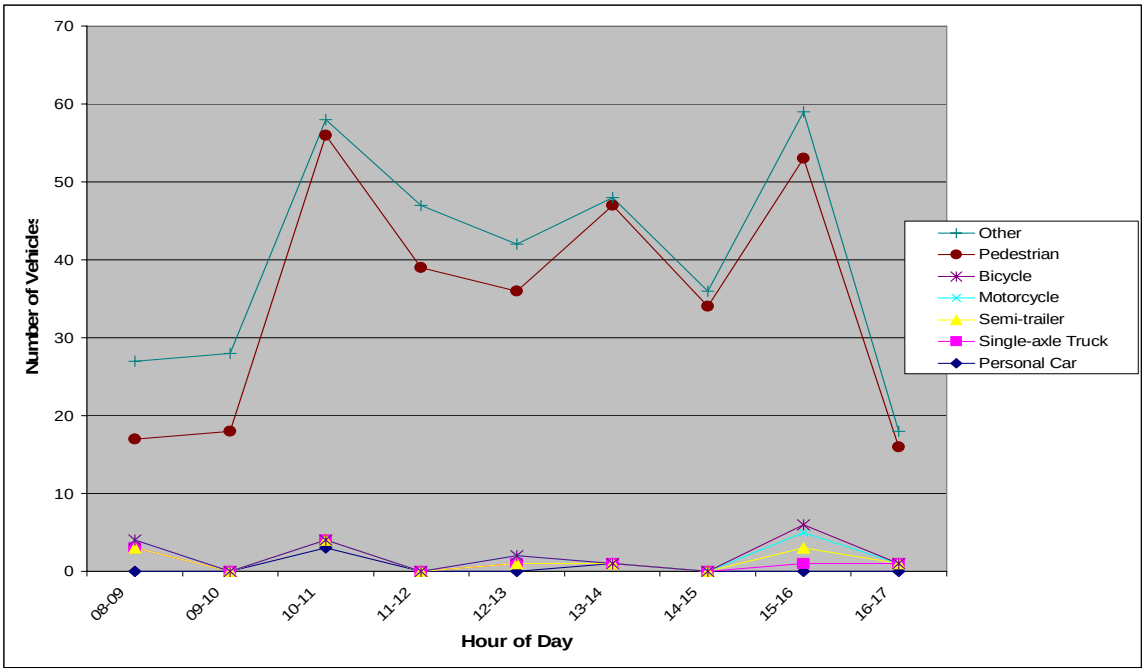
Note: Shows only vehicles with recorded values of one or more.

Figure 2 **Vehicle Traffic Between Fungurume and the Kafwaya Cutoff Road June 14, 2006**



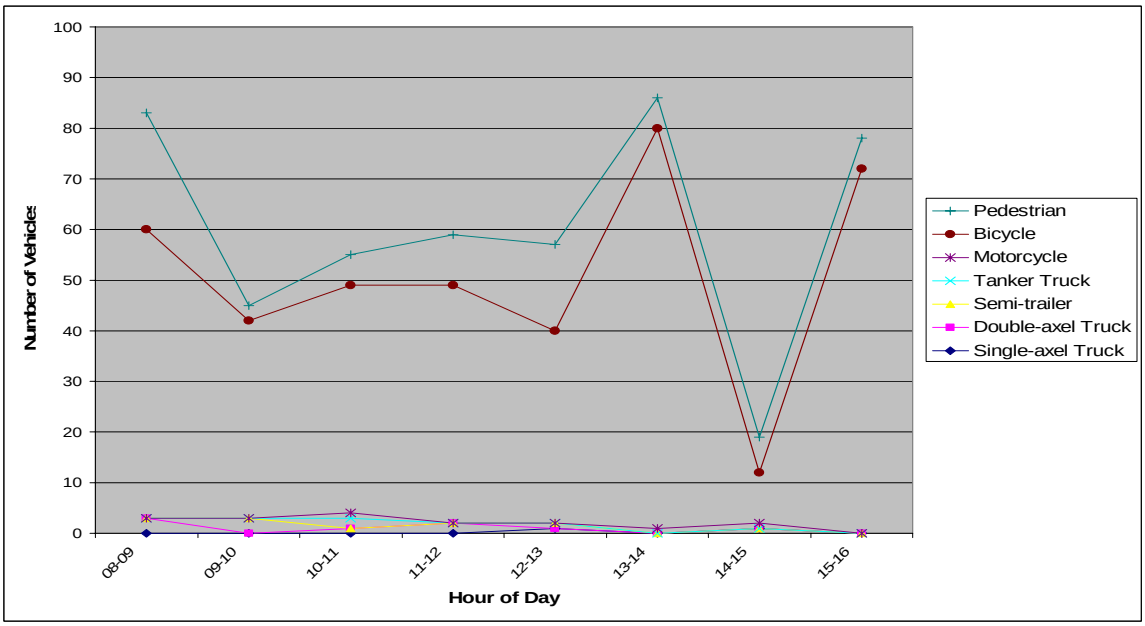
Note: Shows only vehicles with recorded values of one or more.

Figure 3 Vehicles on the Mulumbu Access Road June 13, 2006



Note: Shows only vehicles with recorded values of one or more.

Figure 4 Vehicles on the Mulumbu Access Road June 16, 2006



Note: Shows only vehicles with recorded values of one or more.