Establishing a geochemical baseline for environmental assessment at the Geita mine, Tanzania

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ABSTRACT

Environmental Baseline Assesments (EBAs) characterise the existing environment in and around a mine site. Traditionally, a risk assessment approach has not been applied; however, the application of a tiered risk-based approach is pertinent to an EBA as it ensures that the appropriate data are collected. This methodology offers the advantage of enabling benchmark environmental data to be gathered and placed in a format suitable for future technical evaluation so as to assess potential impacts. The approach considers potential contaminant source, mechanism of contaminant migration and identifies receptors at risk.

At the Geita Gold Mine, in northern Tanzania, a risk-based approach has been applied to a sediment and water quality baseline study. The site is a 470,000 kg (15M oz) Au deposit hosted in Achaean age BIF, part of the Lake Victoria Goldfields. The mine was commissioned in August 2000 and has produced in excess of 31,000 kg (1 million ounces) of gold. Gold occurs in the oxide zone as finely dispersed particles in a goethite-kaolinite-quartz matrix or in the sulfide zone as inclusions in or associated with sulfides, noticeably arsenian pyrite. The area has been subject to sporadic colonial mining (1930-1950's) and later artisan activities (1980's onwards).

As part of the development of the site, a district-wide survey of pre-GGM mining 'baseline conditions' was established through long term monitoring and environmental geology studies. This baseline includes assessment of host rocks and ore environmental geochemistry, particularly acid-generation potential and metal leaching, ground and surface water quality, and background soil and sediment geochemistry. The survey established that relative to conditions elsewhere in the region, the project area shows elevated Pb, As, and Cu due to natural enrichment in the ore zone. Lateritic weathering of the uplands areas also leads to mobility of Fe and Al. The pH of ground and surface water was depressed due to artisan activities on site. Artisan processing have also caused low but widespread mercury *contamination. Finally, poor agricultural practices and artisan mining had caused biological and nutrient contamination. Using the monitoring results from pre-mining through development and early operations (1998-2001), site-specific trigger levels were established for water quality and accepted by the NEMC for reporting monitoring results, based on the results of the risk evaluation. The establishment of the baseline involved bi-monthly sampling, rigorous QA-QC, sample collection and analysis, which, taken together, have produced a robust defendable database with which to monitor environmental impacts on site.*

INTRODUCTION

The assessment of pre-mining concentrations of trace constituents in sediment and water is a challenging tasks in the initial evaluation of a future mine. Such estimates are important in identifying realistic monitoring targets during operations and future remediation goals at the end of mining. At many sites, this is not undertaken, leading to significant problems in determining appropriate remediation levels (Alpers and Nordstrom; 2000; Rees et al., 2001). In previously mined areas, this is further compounded by the impact from previous operations versus “natural” or background levels of metal concentration (Runnells et al., 1992; Davis et al., 2000).

Bedrock geology is a useful indicator of potential pre-mining conditions and environmental assessment can be based on geochemical models related to the geological characteristics of the mineral deposit that is to be exploited (du Bray, 1995; Bowell et al., 2000). The extent and content of environmental investigations applied at a given site develops as the mine evaluation progresses from exploration through to operations (Table 1).

Table 1. Extent of environmental investigation associated with mine development

Mine feasibility stage	**Environmental investigations**
Exploration	Scoping & development of work plan Identify fatal flaws and critical paths
Pre-feasibility	Baseline Assessment; Initiate monitoring program & databases
Feasibility	Impact assessment; permitting and financial assessment
Design	Development of operations procedures and monitoring program
Construction/Operations	Compliance monitoring

The main objective at each stage is to identify and assess likely environmental impacts attributable to mining activity or as a consequence of mine development, initially in qualitative terms but becoming quantitative as development progresses. This can be accomplished by assessing baseline conditions against predicted changes. Equally important is the development of a benchmark against which future environmental changes can be compared and quantified. The nature and intensity of environmental baseline assessment (EBA) varies both with the type of mining, deposit geology, and existing environmental conditions (Keith, 1988; Rees et al., 2001).

Traditionally, mining EBA’s have not been risk assessed and have often focused on only pre-existing conditions. However, the basis of an EBA can be incorporated into a tiered, risk-based framework to optimise the effectiveness of dealing with compliance issues and balancing this with costs. The principles involved in the application of a risk-based environmental baseline assessment (RBEBA) allow the transition between different stages in the environmental investigations of a mine development, as reflected in Table 1, to occur in an efficient manner. It also ensures that all pertinent data is collected at each stage so that an appropriate evaluation can be made.

Selection of specific environmental quality guidelines is generally specific to different jurisdictions. However, as shown by the case study in this paper, they can also be site specific and may require modification of regulatory standards to reflect pre-existing site conditions. Doing this allows realistic indicators of environmental impact to be formulated and used to monitor site operations and to dictate obtainable reclamation goals for closure.

METHODOLOGY

Risk management is a well-established approach, particularly in the context of industrial contamination of both soil and water (Keith, 1988; Rees et al., 2001). Essentially the mechanism comprises two processes: assessment and control.

The risk assessment process is tiered. In the first tier, potential hazards are identified to determine all plausible source-pathway-receptor mechanisms. For a hazard to become a risk, all three (source, pathway, and receptor) are required and need to be linked. The source, by definition, is the hazard; the receptor is the vulnerable entity that will be impacted by contact with the hazard; and the pathway is the means by which the hazard contacts the receptor.

The second tier of the risk assessment involves some judgement as to the potential magnitude of the result of the hazard contacting the receptor. Subsequent tiers involve detailed assessments of the probability of the pathway being attainable by the hazard and potential for hazard contact with the receptor. Once sites are assessed, control measures can be adopted to manage the risk to an acceptable level.

In the application of mining RBEBA, the identification and assessment of hazards require a good understanding of geological and mining processes. For example, in the assessment of tailings seepage (Figure 1), the source or hazard is the chemical constituents released from tailings; the pathway is groundwater flow; and the receptor is a village well. Relating the mechanism shown in Figure 1 to a RBEBA requires understanding the inter-related factors that contribute to the process. A baseline assessment with respect to sediment and water geochemistry essentially aims to quantify the influence of the pre-mining environment on water quality across a project site (Bowell et al., 2000). In the case of a sulfide-bearing mineral deposit, it essentially aims to quantify the influence of mineral weathering on the processes that govern generation of acidic leachate and mobilisation of metals (grouped collectively as acid rock drainage or ARD in this paper).

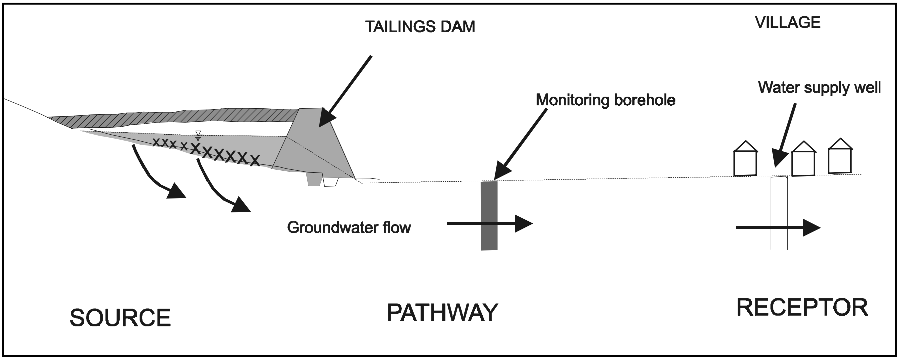

Figure 1. Source-Pathway-Receptor model of tailings seepage

The influence of the underlying, undisturbed geology of a mineral deposit on baseline water quality has been shown to be significant in several studies (Flicklin et al., 1992; du Bray, 1995; Bowell et al., 2000). The geology of a mineral deposit exerts a fundamental control on interaction with the environment. Other important controls such as geochemical and biologically mediated processes, hydrogeology, hydrology, climate, topography, generally modify the environmental effects inferred by the geology. The rationales for sample selection and water quality parameters are based on understanding these controls. The general properties of the different waters were contrasted on the basis of macro-properties such as Eh, pH, and electrical conductivity (Baas Becking et al., 1960; Hem, 1985) as well as trace element chemistry (Keith, 1988; Runnells et al., 1992).

Therefore, the approach that is followed must consider data requirements for the level of risk assessment deemed necessary. Within the context of geochemical and hydrogeological components of a RBEBA analysis, the emphasis is on identifying the plausible links and an appreciation of how these links will be modified as mining progresses. The geochemical components of a RBEBA are selected within a risk-based framework and reflect the geological and geochemical characteristics of the deposit and the mining and mineral processing methods involved. In order to ensure the potential pathways and receptors are included, not just during the EBA but also during operational monitoring, the location of monitoring sites should also be risk based so as to incorporate all potential liabilities in a risk-based framework.

CASE STUDY

Gold has been mined in Tanzania since 1898 in the Geita and the nearby Kahama prospects (van Straaten, 1984). Indeed Geita was the first real gold mine in Tanzania in 1938 and is the largest producer, having produced 27440 kg of gold from 1938-1966 (Barth, 1990). The geology and gold potential of the Geita area has been described by van Straaten (1984), Barth (1990), and Kuehn et al. (1990). Initial modern exploration was conducted in the mid-1990’s when Cluff Resources started prospecting the area around Geita Hill and Nyankanga. In 1996, Ashanti Goldfields accelerated the development, including the Environmental Impact Statement, through the purchase of Cluff. At the end of 1998, a 50% stake in Geita was sold to Anglogold. Prior to initial start up in 2000, the joint venture purchased from Samax, a London-based gold junior company, the Kukuluma concession adjacent to Geita Hill. Since that time, the joint partners have produced in excess of 31,000 kg (1 million ounces) and anticipate producing approximately 19 tonnes of gold (600,000 ounces) per annum.

BACKGROUND ON WATER MONITORING EXERCISE

Baseline water quality monitoring was initiated prior to any development in the area with the establishment of 11 sampling sites in 1997. These were subsequently augmented by inclusion of additional sites in 1998, 1999, and 2000 as the baseline developed along with site development. The final baseline-monitoring program included 17 surface water sites and 18 groundwater sites. Some sites from the initial EIS sampling campaign were abandoned as they were either no longer accessible or had been overprinted by site development, for example in the Nyankanga pit area (Figure 1). In Geita town, some sites were abandoned due to other problems, such as a key missing from a town hand pump padlock or a broken hand pump. The majority of the sites are within the special mining lease (SML) area. However, there are a number of sites, particularly around Geita town and at Nungwe bay that are outside this area.

The baseline was considered complete in 2001 after sampling followed site development. Water quality management still includes quarterly and bi-annual sampling for multi-element analysis at approximately 60 surface and groundwater sites in the mining lease area. This paper deals only with the initial baseline and the implications it has for similar programs.

SITE DESCRIPTION

The Geita goldfields is centred between sub-parallel Nyanzian greenstone belts. The peripheral greenstone belts are characterized by banded iron formation (BIF), felsic tuffs and stratabound-stratiform gold deposits found at the Geita, Kahama and Siga Mabale occurrences (Barth, 1990). The inner zones are lower Nyanzian age and gold deposits; within this are typically shear zone hosted quartz veins, such as Buck Reef and Bulyanhulu. The greenstone belts are intruded by granitoids and dolerites with multiphase deformation in the belts. In most of the area, the BIF crops out on the higher ground whereas the felsic volcanics are exposed along the lower flanks of the ridges, either inter-bedded or alongside the BIF (Figure 2). Extensive leaching and oxidation of the various lithologies under the tropical conditions at Geita has led to the development of a regolith of ferralitic soils. Ferricrete development (cuirass) is extensive in the valley floors, and appears to be ongoing. In comparison, on some slopes, ferralitic soils overlay thick clay sequences with weak cuirass at the top of a massive clay zone and underlying saprolite zone.

Figure 2. Simplified surface geology of the Geita project area

Groundwater is contained in confined aquifer systems within the saprolite horizon and perched aquifers above the ferricrete. Additionally, fractured rock, particularly on the steep hill slopes, can constitute unconfined aquifers where the ferricrete is poorly developed. Springs have developed at the base of these hill slopes.

The bulk of the Geita concession lies within the drainage basin of the Mtakuja River. Initially flowing in a westerly direction along the southern boundary of the concession, the Mtakuja eventually flows to the northwest and ultimately drains into Lake Victoria via a seasonal swamp. The Mtakuja River receives water from the Naymalembo Dam and various perennial streams. Surface water sampling sites for this programme were located along these watercourses.

The area around Geita receives a relatively high rainfall with an average of 1100 mm and annual daily temperatures of 17-30^{0}C. The wet season typically runs from October through May. The majority of people living in the Geita area are subsistence farmers, producing maize, rice, bananas, pineapples, sorghum, and beans. Cash crops grown in the area include cotton and sugar cane. Due to the proximity of Lake Victoria, a small scale fishing industry also exists. In addition, artisan gold mining is common in the area and has produced adverse environmental impacts.

SAMPLING AND ANALYTICAL SUITES

Sampling of surface waters and groundwaters has been undertaken in accordance with a set code of procedures (SRK, 1999a,b). This procedure has been developed using a number of internationally recognised standards such as Australia EPA publications (Keith, 1988; ANZECC, 1992; EPA, 1998). Selection of an analytical suite to characterise the baseline varied over time as site knowledge improved and constrained the list of useful parameters. Initially, a suite of pH (in situ & lab), EC (in situ & lab), Eh (insitu & lab), temperature, alkalinity, Ca, Mg, Na, K, Cl, NO_3, NO_2, PO_4, SO_4, F, Fe, Mn, Al, Cu, Zn, Pb, Hg, Cr, Ni, As, Cd, Mo, Se, Ag, Sn, Te, Sb, U, Bi, and V was used. In addition to this, low level mercury, total suspended solids (TSS) and pathogen indicators, total and faecal coliform counts were determined. The program was reviewed post-EIS and B, Bi, Co, Mn, Mo, Sb, Se, Ag, Sn, Te, U, and V were deleted, as analytical concentrations for these elements were consistently below detection limits, which in all cases were below Tanzanian and WHO guideline values.

Additionally, a field microbiological laboratory was purchased (Delagua lab) for the purpose of field pathogenic indicator analysis. This is considered a more accurate and precise method due to the short storage time demanded between collection and analysis for pathogen analysis (< 24 hours).

To ensure transparency of data obtained during the sampling program, all water quality samples have been sent to external laboratories for analysis. As described above, the laboratories have used international protocols for analysis. Within each sampling campaign suite of samples, at least 1 blank distilled water and two-field sample replicates (as “blind samples”) have been submitted as well. In addition, where practical, a “standard sample” has also been submitted and at least three samples analysed at a second laboratory and the results compared. Sampling locations were established throughout the project area to ensure adequate coverage (Figure A.1 in the Appendix). Only results that were acceptable in terms of reproducibility and accuracy have been used in assessing baseline characteristics.

RESULTS

SURFACE WATER

Surface water chemistry showed little variation in terms of both major and trace element chemistry over the baseline sampling period, apart from areas in the vicinity of artisan workings (SW10 and SW13). Surface waters are relatively dilute, mildly oxidising and trace element concentrations are negligible. As shown in Table 2, most baseline surface water sites showed parameters that exceeded at least one of the parameters issued in regulation 12 of the Mining Act (1999) for mining effluent (most commonly, pH and Fe, Figure A.2 & Figure A.3).

Table 2. Parameters exceeded in surface waters

	Regulation 12 water standards (Mine Act, 1999)		**WHO**
	Effluent trigger levels	**Receiving water trigger levels**	
SW1	Fe, Pb	Fe, Ni, Zn, Pb	Al. Fe, Mn, Ni, Pb, Zn, Cl,
SW2	Fe,Pb	Cr, Fe, Ni, Pb	Cr, Fe, Mn, Ni, Pb, FC, TC
SW3	Fe, pH	Fe, Ni, pH	Al, Fe, Mn, Ni, NO_3
SW4	Fe	Fe, Ni, Zn	Al, Fe, Ni, NO_3
SW5	Fe	Fe, Ni	Al, As, Fe, Mn, Ni, NO_3, TC, FC
SW6	Fe, Pb	Fe, Ni, Pb, Hg, SO_4	Al, Fe, Mn, Ni, Pb, TC, FC
SW7	Fe	Fe	Al, Fe, SO_4, NO_3
SW8	Fe	Fe	Al, Fe, Mn, NO3,
SW9	Fe, Pb	Fe, Ni, Pb, SO_4	pH, Al, Fe, Ni, Pb, SO_4, NO_3, TC, FC
SW10	Cr, Fe, Ni, Zn, Hg, pH, SO_4	Cr, Fe, Ni, Zn, As, Hg, pH, SO_4	TDS, Al, As, Cr, Fe, Mn, Ni, SO_4, TC
SW11	Fe, Pb, pH	Fe, Ni, As, Pb, Hg, pH	Mn, Fe, Al, Ni, Pb, TC, FC
SW12	Fe, Pb, pH	Fe, Ni, Pb, Hg, pH	Al, Fe, Ni, Pb, FC
SW13	Fe, Pb, Hg, pH	Fe, Ni, Pb, pH	Al, Fe, Ni, Pb, TC.
SW14	Fe, Pb, pH	Fe, Ni, Pb, Hg, pH	Al, As, Fe, Mn, Ni, Pb, SO_4, TC, FC
SW15	Pb	Fe, Pb	Al, Pb, TC, FC.
SW16	Pb	Ni, Pb	Al, Fe, Ni, Pb, TC.
SW17	Fe, Ni, Pb, pH	Fe, Ni, Pb, pH	Al, Fe, Mn, Ni, Pb, TC, FC.
SW18	Fe, pH	Fe, pH	Al, Fe, TC, FC.
SW19	Ni, Pb	Ni, Pb	Al, Ni, Pb, TC, FC.
SW20	Fe, Pb	Fe, Ni, Pb	Al, Fe, Ni, Pb, TC, FC.
SW21	Fe, Pb	Fe, Ni, Pb	Al, As, Fe, Ni, Pb,
SW22		Fe	Fe
SW23	Fe	Fe	Fe

The parameters most commonly in exceeding standards are Fe, Pb, and Ni. Iron anomalies are related to lateritic weathering that release silicate-held or sulfide-held iron to colloidal ferric hydroxide as part of the “ferrolyis” process (Mann, 1983; Thornber, 1992). Lead and nickel are trace elements associated with the gold-bearing sulfide mineralization. The source of this “natural contamination” is the erosion of iron-rich soils, a natural geological mechanism in tropical climates (Mann, 1983). The iron is predominantly present as ferric oxyhydroxide, which has a high capacity to sorb trace metals such as Ni and Pb into the crystal lattice (Stumm and Morgan, 1982). Additionally, it has a strong potential to scavenge oxyanions, such as $[AsO_4]^{3-}$ through surface attraction as pH changes. This is the reason that for some trace elements, higher concentrations were observed in the unfiltered samples than the filtered ones. Additionally, the hydrolysis of ferric iron releases acidity as protons (H^+). Thus, water pH is depressed, as observed.

Coliform counts exceed the WHO guideline of no detection at the majority of sites, indicating the prevalence of faecal contamination. However, this issue is related to poor sanitation in the region and is unrelated to mining. GGM will not contribute to this as the mine site and residences have adequate provision for human sanitation and disposal of domestic waste.

GROUNDWATER

As with surface waters, there has been no distinct change in water chemistry during the baseline-sampling program. Groundwater chemistry is characterised by slightly lower pH, higher TDS and more widespread detection of Fe and other trace metals than the surface water. Relative to regulation 12 standards, most sampled sites exceed at least one of the specified parameters (Table 3). As noted for surface waters, Fe and pH standards are exceeded at the majority of sites, while Pb also commonly exceeds regulatory limits in groundwater samples (Figure A.4). Other parameters less frequently in exceedence are NO_3, SO_4, As, and Cr. As would be expected from the magnitude and widespread detection of coliforms in the surface waters, the groundwater sampling locations exceeded the WHO guidelines for this factor at all but 6 of the sampling sites. The causes for these elevated levels are the same as explained above for surface waters, including the tropical weathering (Bowell et al., 1996) and poor sanitation in the vicinity of Geita town.

MINE WATERS

Table 4 summarises the mine water parameters that exceed the standards provided in regulation 12 of the Mining Act (1999). In comparison to both surface and ground water baseline conditions, the mine water exceeds a far greater number of regulation 12 values. Also, the magnitude of the problem is generally greater. For instance, mine water from sample site GA2/4 has a pH as low as 2.59 coupled with a maximum TDS concentration of over 14000 mg/L, which includes over 1500 mg/L total Fe and 10700 mg/L SO_4. The concentrations of TDS, Cr, Cu, Hg, Ni, and Pb exceed the effluent standard in regulation 12 at GA2/4. Similar problems exist at the other mine water sampling sites. Faecal contamination is also present at the mine water sampling sites.

The mine waters have obviously been contaminated by sulfide oxidation, which generates acid and causes the release of metals. However, this is greatly exacerbated by the artisanal miners who disperse sulfide-bearing rock at the surface and deposit remnants into surface watercourses and around mine water discharges during gold recovery activities. Additionally, they introduce mercury and sulfate into the water and environment at the sites (Figures A4-A5 respectively). Poor sanitation in the vicinity of the artisanal townships causes elevated coliform counts at all sites. This situation was greatly improved by the relocation of artisanal miners from the site during site construction.

Table 3. Parameters exceeded in groundwater

	Regulation 12 standards		**WHO**
	Effluent TL	Receiving Water TL	
GWA	pH, Fe, Pb	pH, Fe, Ni, Pb	Al, Fe, Ni, TC, FC.
GW1	pH, Fe, NO_3	pH, Fe NO_3	Fe, NO_3, TC, FC.
GW2	pH, Fe, Pb, NO_3	pH, Fe, Pb, NO_3	Al, Fe, Mn, Ni,Pb, NO_3, TC, FC.
GW3	pH, Fe	pH, Fe, Ni, Zn	Al, Fe, Ni, Pb, TC, FC.
GW5	pH, Pb	pH, Ni, Pb	Al, Fe, Mn, Ni, Pb, TC, FC.
GW6	Fe, pH, Pb	pH, Fe, Ni, Pb	Al, Fe, Ni, Pb, TC, FC.
GW7	-	-	-
GW8	-	-	-
GW9	Fe, Cu, As, SO_4	Fe, Cu, As, SO_4	As, Fe, SO_4, NO_3, F
GW11	pH	pH, Ni	Al, As, Mn, Ni, Pb, Zn, TC, FC.
GW12 N	pH, Fe, Zn Pb	pH, Fe, Ni, Zn Pb	pH, Al, As, Fe, Ni, Pb, FC.
GW12 S	Fe, Pb	Fe, Ni, Pb	Al, Fe, Mn, Ni, Pb, FC.
GW13 E	Fe, Pb, pH	pH, Fe, Ni, Pb	Al, Fe, Ni, Pb, TC, FC.
GW13 W	Fe, Pb, pH	pH, Fe, Ni, Pb	Al, Fe, Mn, Ni, Pb.
GW14 E	Fe, Pb, pH	pH, Fe, Ni, Pb	Al, Fe, Mn, Ni, Pb.
GW14 W	Cr, Fe, Pb	Fe,Cr, Ni, Pb	Cr, Fe, Ni, Pb.
GW15 E	-	-	-
GW15 W	Fe, Pb	Fe, Pb.	Al, Cr, Fe, Ni, Pb, TC, FC.
GW16 E	pH, Fe, Pb	pH, Fe, Pb	pH, Fe, Pb, TC, FC.
GW16 W	pH, Fe, Pb	pH, Fe, Ni, Pb	Al, Fe, Ni, Pb.
GW17	Pb, pH	pH, Ni, Pb	Al, Mn, Ni, Pb, FC, TC.
GW18	Pb, pH	pH, Ni, Pb	Al, Ni, Pb.
GW19	pH	pH.	-
GW20	-	-	-
GW21	-	-	-

Table 4. Parameters exceeded in mine water drainage

Site	**Regulation 12 standards**		**WHO**
	Effluent TL	**Receiving water TL**	
GA4/1	Fe, Pb, SO_4.	Fe, Ni, Zn, Pb, SO_4.	Al, As, Fe, Mn, Ni, Pb, SO_4, TC, FC
GW4	pH, As, Fe, Pb, NO_3, SO_4	pH, As, Fe, Ni, Zn, Pb, NO_3, SO_4	pH, Al, As, Fe, Mn, Ni, Pb, SO_4 ,F, TC, FC
GW10	pH, As, Fe, Pb, SO_4	pH, As, Fe, Ni, Zn Pb, NO_3, SO_4	Al, As, Fe, Mn, Ni, Pb, SO_4, F, TC, FC
GA3/1	-	-	Al, Fe, Mn, NO_3
GA2/4	pH, TDS, Cr, Fe, Ni, Cu, Zn Pb, As, SO_4	pH, TDS, Cr, Fe, Ni, Cu, Zn Pb, As, SO_4	pH, TDS, Al, Cr, Cu, Fe, Hg, Mn, Ni, Pb, SO_4, F

DISCUSSION

The results of this hydrochemical baseline study at the Geita Mine Site highlighted the fact that surface and ground water baseline conditions prior to the onset of current mining were in exceedence of a number of parameters specified by regulation 12 of the Mining Act (Table 5). As the aim of the monitoring is to evaluate future impacts associated with current operations, the comparison basis needed to be changed to incorporate the results of baseline geochemical analysis.

Table 5. Proposed trigger levels for Geita mine operations

Parameter	**Regulation 12 standards, receiving water trigger levels**	**Exemption value from baseline*for site-specific trigger level**
pH, su	6.5-8.5	
TDS, mg/l	2500	*
TSS, mg/l	60	*
BOD, mg/l	3.5	**
Chloride, mg/l	170	
Sulfate, mg/l	500	*
Ammonia, mg/l	0.35	
Nitrate, mg/l	35	***
Cyanide, mg/l	0.75 (effluent trigger level)	
Cyanide-WAD mg/l	0.35 (effluent trigger level)	
Cyanide-free mg/l	0.075 (effluent trigger level)****	
Oil & grease, mg/l	0.35	
Phenols, mg/l	0.0015*****	
Arsenic, mg/l	0.05	*
Cadmium, mg/l	0.04	
Chromium, mg/l	0.04	*
Copper, mg/l	2.5	*
Iron, mg/l	2	33*
Lead, mg/l	0.075	0.2*
Mercury, mg/l	0.00075	0.02******
Nickel, mg/l	0.04	0.2*
Zinc, mg/l	0.15	*

Notes for Table 5:

*This excludes “mine waters” from the old adits that in the baseline contained numerous exceedences.

**Due to problems with holding times of samples, it was not possible to get accurate measurements of BOD during baseline. Field meters to measure BOD are insensitive so field measurements are necessarily valid. On the basis of site coliform measurements, it can be assumed that BOD in background surface waters generally exceeds 5 mg/L and where local habitation exists, considerably higher, with >250 coliforms/100 mL being encountered consistently at several sites. BOD measurements were exempted and total and faecal coliforms in the area used in place; an increase above baseline measurements in these parameters was established as a trigger level.

*** Poor sanitation in the vicinity of Geita town leads to seasonal nitrate values in excess of 35 mgL. Therefore, this trigger value should only be applied to site drainage at the compliance point.

**** Due to problems with sample holding time, GGM believed it unlikely that a laboratory would be able to report free CN concentrations at this detection limit and that a more appropriate trigger level would be 0.1 mg/L

***** Due to problems with sample holding time, GGM believed it unlikely that a laboratory would be able to report phenol concentrations at the detection limit and that a more appropriate trigger level would 0.04 mg/lL (after extraction)

****** Mercury levels in waters around the Geita site are unrelated to activities of GGM but are directly attributable to artisan miners, as proven in the water quality baseline studies. Consequently, GGM argued that this trigger level should only be adopted once artisan miners had finally left the site. The long history of artisan processing of gold ore had impacted mining in the area at many of the monitoring sites; consequently, both sediment and water Hg concentrations are elevated. GGM therefore requested a higher trigger level that took into account the baseline study results.

Using this baseline, appropriate site-specific guideline values were defined by estimating background level and potential risk. In general, the majority of exceedences observed on site could be attributed to historical artisan activity on site; this should decrease over time as artisans were relocated during mine development. The site-specific trigger values were adopted in 2001 and currently form the basis of operational monitoring control to evaluate potential impacts and also identify potential risk receptors and pathways. On the basis of the monitoring program, potential pollutant pathways and receptors were identified (Table 6), based on geochemical analysis and sampling of groundwater, surface water, mine waters and sediments from the project area, as well as domestic water and spent process water from artisan workings.

CONCLUSIONS

Traditionally, EBA’s have not been risk based. However, using a risk-based framework to integrate aspects of an EBA offers huge advantages in the development of benchmark environmental standards, and allows the assessment of collated data. The approach considers potential contaminant source, mechanisms of contaminant migration along pathways, and can be used to identify potential receptors. In addition, detailed assessment of contaminant migration will also highlight potential attenuation mechanisms that exist and that could be developed in order to provide further control and control risk. The methodology can be applied to any mine site, in any geological setting. At the Geita Gold Mine in Tanzania, the development of such a program has successfully been used to create a robust and defendable baseline and monitoring program to assist Geita Gold Mine with water and environmental management both during operations and closure.

Table 6. Summary of some potential hazard-pathway-receptor links identified at the Geita Gold Mine

Source	**Pathway**	**Receptor**
Acid generating minerals through sulfide oxidation or dissolution of secondary acid generating or metal-releasing sulfate phases	Flushing of acid generating minerals during rainfall through vadose zone	Surface water
		Groundwater
		Sediments
	Transport of contaminants by groundwater flow	Domestic water supply wells
		Make-up water supply via groundwater
Cyanide useage during mineral processing	Spill or release of cyanide and migration into vadose zone	Surface water
		Groundwater
		Aquatic species
	Contaminant transport in groundwater	Domestic water supply wells
		Make-up water supply via groundwater
Mercury contamination from artisan mining	Spill or release and migration into vadose zone	Surface water
		Groundwater
		Aquatic specie
	Contaminant transport in groundwater	Domestic water supply wells
		Make-up water supply via groundwater
	Sublimation of mercury during gold refining	Direct inhalation of fumes
		Dust deposition on flora

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Figure A.1: Sampling location

Figure A.2 Iron, mg/l


N
GEITA FOREST RESERVE
410000
400000
390000
KEY
SW1 SAMPLE No.
SURFACE WATER SAMPLE
GROUNDWATER SAMPLE
MINE WATER SAMPLE

Figure A.3:pH

Figure A4: Lead, mg/l

Figure A5:Mercury, mg/l

Figure A6: Sulfate, mg/l