Case Study of Geita Gold Mine: An Example of Proactive AMD Mitigation Performance

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ABSTRACT

Initial characterization at Geita Gold Mine (GGM) identified that ~38% of waste rock materials are potentially acid forming (PAF) and tailings are sulfidic (~4% pyrite). GGM has historical acid and metalliferous drainage from naturally-exposed sulfidic rocks and artisanal mining. Pre-mine groundwater studies indicated elevated concentrations of lead and iron, with bores in areas of known mineralization indicating elevated sulfate, arsenic, chromium and nitrate. During mine operation waste rock has contributed limited sulfate and metals. The mine's closure plan for the waste rock is to encapsulate the PAF waste rock within a buffer zone of non-acid forming (NAF) waste rock. The waste placement plan was developed prior to and in the early stages of mining based on geochemical characterization, mapping, and pit block modelling and is reconciled against the updated waste block model as mining progresses. The mine actively minimizes the infiltration of water into the waste rock materials using truck compaction of each dump lift and progressive reclamation.

This paper outlines the approach to designing cover systems and landforms suitable for final closure of the waste storage facilities. A detailed geochemical and geotechnical material characterization program of the current waste storage landforms, consisting of material sampling and field and laboratory testing was undertaken. The results of groundwater and surface water analyses indicated that the waste rock dumps are most likely constructed and behaving as designed with respect to PAF encapsulation. Thus, the conceptual model developed was that a cover system that resulted in moderate net percolation rate, coupled with a stable (geotechnical and geomorphologic) landform that properly managed surface water, was sufficient for reducing contaminants in downstream receptors to below discharge standards. The conceptual model was confirmed using soil-plant-atmosphere, groundwater flow, and contaminant transport numerical modelling to evaluate the predicted long-term water quality.

Keywords: PAF encapsulation, cover design, geochemical characterization, landform design, contaminant transport

INTRODUCTION

The modern Geita Gold Mine (GGM) owned by AngloGold Ashanti Ltd. and operated by Geita Gold Mining Ltd. is an open-pit mine situated in the Mwanza Region of north-western Tanzania, approximately 90 km from the regional capital of Mwanza and 20 kilometres south of Lake Victoria, in an area known as the Lake Victoria Goldfields.

GGM's broad reclamation objective is to leave the site in a condition that is safe, stable, and minimizes long-term environmental impacts as well as providing opportunities for alternative forms of business development. The project described in this paper was initiated to develop mitigation methods for the waste rock and tailings storage facilities that would result in GGM meeting or exceeding their stated reclamation objectives. GGM's closure criteria to meet these objectives for the waste storage facilities were the creation of stable landforms and the reduction of solute loading from the waste storage facilities to meet discharge standards at the downstream compliance points.

Prior to the onset of mining, GGM developed a waste placement plan for the waste rock storage facilities to proactively mitigate against AMD production. This involved detailed characterization of the future waste rock material into non-acid forming (NAF) and potentially acid-forming (PAF) categories (which are continuously updated during mining). The waste rock storage facilities were then designed to encapsulate the PAF materials.

It was hypothesized that a cover system and landform design using the locally-available borrow materials would reduce net percolation to a moderate level (10-15% of mean annual rainfall) in the waste rock and tailings materials and that this would be sufficient to reduce the solute loading at the downstream receptors to below discharge standards. This paper describes the support studies used to verify this hypothesis.

BACKGROUND

The modern Geita Gold Mine began to process ore mid-2000. The GGM operation comprises three mining areas: one centred on the old Geita Hill area (Geita Block) comprising several pits: Nyankanga, Geita Hill, Lone Cone and their associated waste rock dumps: WD1, WD5, WD6, WD14, WD15, the Nyamulilima Block is west of Geita Hill and comprises Star & Comet, Robert and Ridge 8 and waste rock dump WD16, and the third – Kukuluma Block, located ~20km away comprising the Kukuluma and Matandani pits and waste rock dumps WD7, WD8 and WD9. Tailings have been deposited in an historic TSF constructed prior to the current mining operation and referred herein as the Old TSF and a modern storage referred to as the New TSF (NTSF). The materials' composition in these landforms has the potential to generate acidic drainage from natural oxidation of contained sulfidic minerals and result in metal leaching. Previous characterization has shown up to 38% of waste rock materials as potentially acid forming (PAF), based on initial assessment in 2001 (Scott et al, 2014). Currently gold is mined from Nyankanga, Geita Hill and Star & Comet Pits. Kukuluma and Matandani pits and the Lone Cone pits are not operational. The current life of mine is planned until 2030.

Geology

GGM is located in the Geita Greenstones that form the northern arm of the regional Sukumaland Greenstone Belt of the Archaean Tanzanian Craton. Stratigraphically the Sukumaland Greenstone Belt belongs to the Neoarchaean Nyanzian Supergroup (Barth, 1990; Borg and Shackleton, 1997). The Geita deposits are hosted in Archaean-age rock Upper Nyanzian formations characterized by banded iron formation (BIF), felsic volcanics and andesite/diorite lithologies (Sibilski and Stephen, 2006). The BIF outcrops in all of the high ground in the area, while felsic volcanics occur in the lower flanks of the ridges and are either inter-bedded within the BIF or occur either side of it. The other main lithology in the Geita area is a trachyandesite, encompassing a suite of volcanic rock types, ranging from basalt to diorite in composition. The trachyandesite units are commonly interbedded and folded with the BIF. The volcanics, which host the gold mineralization, have been metamorphosed to lower greenschist facies. At Nyankanga the principal waste rocks are microdiorite and BIF. The Kukuluma host waste rock sequence is more variable and includes mafic to felsic volcanics, BIF and metasediments. The western section of the belt, in the GGM area, is cut by regional scale Proterozoic quartz-gabbro dykes with a strong north-east trend. The area is dominated by both NW and NE structural trends, with a weaker NNW trend occupied by Karoo dolerite dykes. The greenstone belts of the Tanzanian Craton are characterized by more localized and discontinuous structures.

Mineralogy

Gold mineralization is typically associated with quartz veins (inner belts) and disseminated sulfides (outer belt) in quartz-carbonate-chlorite shear zones replacing and crosscutting magnetite-rich BIF. Gold mineralization can also be associated with massive and disseminated sulfide bodies on contacts between felsic tuffs and BIF. The principal sulfide present in the shear and vein-hosted deposits is pyrite, with minor pyrrhotite and trace arsenopyrite, chalcopyrite, galena and sphalerite. Gold occurs as free native gold in quartz veins and as inclusions or surface adherents to iron sulfides. Carbonate minerals that are present in the mine sequence are dominated by calcite with accessory dolomite, ankerite and siderite. The carbonates occur as fine-grained pervasive mineralization in the altered BIF matrix and as coarser-grained calcite in veins. The supergene mineral assemblage is dominated by oxyhydrates of iron and aluminium.

Climate and Hydrology

The Geita District has a highland equatorial wet-dry weather pattern with a bimodal wet season (generally October to December and February to May) with a mean annual rainfall of ~980 mm. A distinct dry season extends from June to August/September with an average annual pan evaporation of ~1,300 mm. The areas annual minimum and maximum temperatures are between 14°C and 32°C. The average altitude is 1,180-1,350 m ASL for Nyankanga and Geita Hill-Lone Cone site, 1,550-1,620 m for Kukuluma-Matandani mine site and 1,450-1,500m ASL for Nyamulilima Star & Comet site to the west.

The main GGM operations (Geita Block) are located within the Mtakuja River catchment that drains to Lake Victoria 25 km to the northwest. Surface water enters the main Nyankanga and Geita Hill-Lone Cone site from the southeast via a dam diversion of the Nyankanga River, which diverts water and outlets to the Mtakuja River. The Mtakuja River runs through the main mine site between the NTSF and WD1 and continues northwest towards Lake Victoria. Surface water runoff from the upland ridges and ferricrete areas can be high, and under heavy rainfall conditions can produce fast response flows within surface water channels.

Two hydrogeological units have been identified in the main GGM site area that act to transmit the majority of groundwater seepage: transported ferricrete and saprock. The transported ferricrete acts as a shallow, unconfined aquifer, while a deep aquifer exists within the basement rock profile (saprock and fractured bedrock). The saprolite unit generally acts as an aquitard between the shallow and deep aquifers.

Waste Management Plan

The presence of sulfides in the host rocks to the GGM gold mineralization necessitated a set of waste management procedures be developed prior to commencement of mining to ensure effective waste rock storage facility (WRSF) design and correct placement of reactive (PAF and metal leaching) waste to minimize and manage AMD as outlined in Scott et al, 2014. These procedures included:

- Waste rock and tailings characterization using acid base accounting (ABA), metals analysis, and kinetic testing of representative waste rock and ore;
- Construction of the geological model of the waste;
- Block modelling of waste rock and merging with the ore resource model;
- Validating the waste model using in-pit geological mapping;
- Selective handling and placement of waste in designated areas of the WRSF and the NTSF embankments;
- Validating placement of waste within the WRSF and tailings dam embankment;
- Monitoring for success of placement using piezometers within the WRSF, tailings embankment and downstream of these facilities;
- Regular technical reviews monthly (internal), three to six monthly (external);
- Implementing these procedures for LOM.

The WRD design facilitates PAF encapsulation, with a NAF base layer 10-20 m thick, PAF placed in the middle of each dump lift, and an outer NAF layer between 80 and 100 m on each dump lift to complete the encapsulation. The basal layer is constructed by paddock dumping and then worked with a dozer to form the flattened base layer. Tipping of PAF material within the internal part of the dump is commonly undertaken by paddock dumping and worked continually by dozer to form the dump lift. Tipping of NAF material to form the outer layer is usually done at 35-37° batter angle depending on type of material (oxides to fresh), interspersed with 36 m wide berms at 20 m vertical increment lifts and the final batter angle is <20°.

METHODOLOGY

To verify the hypothesis, that a cover system and landform design that resulted in an average net percolation rate of 10-15% and a reduction in erosion would meet GGM's closure objectives, a number of studies were undertaken, including:

- Site visit and material characterization (geotechnical and geochemical);
- Surface and groundwater quality data assessment; and
- Soil-plant-atmosphere modelling, seepage and solute transport modelling, erosion modelling, and landform evolution modelling.

Site Visit and Material Characterization

A site visit and material sampling program was conducted at GGM in the fall of 2012. Samples of waste rock, tailings, topsoil, and laterite borrow material were sampled both for geochemical and geotechnical characterization. Material samples were sent to laboratories in both Australia and Canada for further detailed testing. The material characteristics were used refine the conceptual model and were used to develop input parameters for the numerical modelling. The geotechnical parameters measured were particle size distribution, gravimetric water content, Atterburg limits, specific gravity, saturated hydraulic conductivity, and the water retention curve. The geochemical testing included acid base accounting, metals geochemistry, and short-term leach testing.

Surface and Groundwater Quality Data Assessment

A review and compilation of the water quality monitoring data collected by GGM for the three distinct mining areas within the GGM licence area was undertaken to provide background in regards to water quality, hydrology, hydrogeology, the effects of AMD, and hence the information for a holistic approach to AMD management at the GGM.

Two mine pits (Matandani and Kukuluma) that have ceased operation and are filling with groundwater are impacted by AMD and contain significant acidity and metals. Downstream of WD7 and WD9 (Kukuluma/Matandani) the chemical signature is Ca, Mg, and HCO_3 dominated. This is typical of the background chemistry in the area indicating WD7 and WD9 are not significantly acid forming.

Another significant source of AMD is the toe seep derived from WD1 (SW37/SW37a). Treatment of the seep was implemented in 2010 and monitoring results suggest that water quality in the area has improved in recent years, which is represented by a drop in sulfate and TDS concurrent with an increase in pH.

The NTSF that was commenced in 2000 shows that a change in water quality has occurred with time for key indicators Ca, Na, sulfate, alkalinity, and TDS. While the concentrations for these analytes is above the concentrations recorded for upstream surface water monitoring sites they remain below the GGM discharge standards. Further, the concentrations vary over the year with higher concentrations occurring in the drier months of May to August and lower concentrations occurring in wetter months of October to April, a pattern that has remained consistent since 2005. The chemical signature of groundwater upstream and downstream of the NTSF is dominated by Na, K, Ca, Mg, SO_4 and HCO_3. Below the NTSF increases in sulfate concentration in groundwater occurs locally. Concentrations are below GGM discharge standards.

There are no surface water data for upstream of the WD1 facility, but it is expected to be similar to surface water quality upstream of the NTSF. Below WD1 surface water is low in major cations, chloride, sulfate and metals; above concentrations in waters upstream of the TSF; but below GGM discharge standards. Monitoring data for groundwater upstream of WD1 are not available; however, the chemical signature upstream of WD1 is expected to be similar to that upstream of the NTSF i.e. dominated by Na, K, Ca, Mg and HCO_3. Downstream of WD1 the groundwater is dominated by Ca and HCO_3, which suggests WD1 has minimal influence on groundwater.

Further down gradient, the groundwater compliance monitoring point has a similar chemical signature to the upstream NTSF suggesting WD1 has a minimal effect on groundwater chemical composition. Although it should be noted that the meq/L concentration at the groundwater compliance site is double the upstream NTSF concentration. Further down gradient, the surface water compliance monitoring point chemical signature is dominated by Na, K, Ca, and SO_4. This is consistent with influence from both the NTSF surface and groundwater.

From the data set available, the Star and Comet area appears to have been affected by artisanal workings, although the water quality appears to be improving. The Star and Comet groundwater has a chemical signature dominated by Ca and HCO_3. The surface water chemical signature is similarly dominated by Ca, Na, K, and HCO_3. This suggests mining at Star and Comet has a relatively minor effect on chemical signature.

Overall there is relatively little exceedance of discharge limits in groundwater across the GGM site. Sites that have generated AMD (including the Kukuluma Pit and Matandani Pit; and the toe of WD1 (SW37) up to 2011) have historically exceeded compliance limits for a number of trace metals, however ongoing data may show these metals are now compliant. Most other sites show evidence of sulfide oxidation in either elevated sulfate concentration and/or elevated Fe, Al, or trace metal concentrations. However typically these sites are circum neutral pH with relatively low acidities possibly driven by Fe^{2+} or residual Al.

Source-Term Development

Source terms were developed for sulfate (SO_4), chloride (Cl), and fluoride (F) as conservative analytes for modeling purposes. They were derived from results from short term leach tests on samples collected from WD1 and the new tailings storage facility as part of this study as well as from comparison with surface and groundwater monitoring data from 2000-2012. The waste materials were divided into three types for the development of source terms: WD1 NAF waste rock, WD1 PAF waste rock, and new tailings. Source terms for the waste materials, as well as discharge limits defined by the Tanzania Bureau of Standards (2006), ANZECC (2000, 2011), and GGM, are shown in Table 1.

Numerical Modeling Assessments

Numerical modeling tools were used to verify the conceptual model of the site and to evaluate various cover system and landform designs for the waste storage facilities. The evaluations included soil-plant-atmosphere modeling, seepage and solute transport modeling, and erosion and landform evolution modeling.

Table 1 Summary of source terms and water quality guideline values used in modeling.

Source	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)
WD1 – NAF Waste Rock	276	59	0.65
WD1 - PAF Waste Rock	960	59	0.65
Tailings - Base Case	588	41	0.65
Tailings - Elevated Sulfate	1590	41	0.65

Source	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)
Guideline Values			
ANZECC – Livestock	1000	n/a	2
ANZECC – Drinking water (health)	500	n/a	1.5
GGM discharge standards (Tanzania)	500	200	8

Cover Design Conceptual Model

A spectrum of achievable net percolation (NP) rates using a cover system was developed for GGM based on available materials and quantities, the vegetation potential, the local climate, and the landform. Four levels of NP rates were developed for the conceptual categories of “very low”, “low”, “moderate”, and “high” NP. Table 2 summarizes these four levels, as well as the conceptual cover system designs that are anticipated to achieve each NP level at GGM.

The locally-available borrow materials at GGM are a laterite material (which is highly variable). Based on laboratory measurements, an appropriately-compacted layer, utilizing the laterite materials that contain a higher clay percentage, could achieve a saturated hydraulic conductivity (k_{sat}) of ~5 x 10^{-6} cm/s. A non-compacted layer of laterite material could achieve a k_{sat} in the range of 5 x 10^{-3} to 1 x 10^{-5} cm/s and act as a growth medium and to achieve store-and-release of infiltrating water.

Using a cover consisting of 0.3 m of compacted laterite overlain with a 0.5 m thick layer of non-compacted laterite, a low net percolation rate of 10% of mean annual rainfall could likely be achieved. Alternatively, using a cover consisting of a layer of non-compacted laterite between 0.5 m and 1.0 m thick, a moderate net percolation rate of 15% of mean annual rainfall could likely be achieved. The conceptual model assumes that water will be managed on the plateaus and slopes to prevent erosion and that there will be upland diversion to prevent upland water running onto the landform.

The production conceptual model assumed for AMD generation from the waste materials was a direct linear relationship between solute loading at the base and net percolation rate at the surface (i.e. a constant concentration model). The source terms developed based on the surface and groundwater quality assessment (Table 1) were used to complete the conceptual model for GGM.

Table 2 Spectrum of achievable net percolation (NP) rates for conceptual cover system design options for the GGM waste storage facilities.

NP Level	NP (%)	Conceptual Cover System Design	
		Plateau Areas	**Batter Slope Areas**
Very Low	< 5%	Geosynthetic product or 0.3 m compacted clay (10^{-7} cm/s) and 0.5 m non-compacted growth medium	0.3 m compacted clay (10^{-7} cm/s) and 0.5 m non-compacted growth medium

Low	5 to 10%	0.3 m compacted laterite ($\leq 5x10^{-6}$ cm/s) and 0.5 m non-compacted laterite	0.3 poorly-compacted laterite and 0.5 m non-compacted laterite
Moderate	15 to 20%	0.5 non-compacted laterite	0.5 non-compacted laterite
	10 to 15%	1.0 m non-compacted laterite	1.0 m non-compacted laterite
High	>20%	<0.5 m non-compacted laterite	<0.5 m non-compacted laterite
	25 to 35%	Uncovered waste rock or tailings	Uncovered waste rock or tailings

Soil-Plant-Atmosphere Modeling

Soil-plant-atmosphere modeling using VADOSE/W was completed to confirm the conceptual model; in particular, this assessment was used to predict performance (in terms of net percolation) of various cover system designs for the waste materials. A 100-year climate database and estimates of key vegetation characteristics were developed for the modeling program. Material characteristics were developed from the results of the geotechnical characterization program.

The results of the soil-plant-atmosphere modeling confirmed the conceptual spectrum of cover performance shown in Table 2. The modeling indicated an improvement in performance when the non-compacted laterite thickness was increased from 0.5 m to 1.0 m but showed performance levelling off for thicknesses greater than 1.0 m. This result was due to the higher available water holding capacity in the thicker cover layer and greater volumes available for evapotranspiration (but this benefit tapers off in thicker layers when the water gets too deep for roots). The modeling also showed an increase in performance on the slopes for all cover types due to increased runoff rates. Thus a coarser-textured material could be used on the slopes, if required for erosion control, and performance of 10% net percolation could still be expected.

Seepage and Solute Transport Modeling

Both 3-D and 2-D seepage and solute transport modeling programs were completed to confirm the hypothesis that a cover system resulting in a net percolation rate of 10%, together with the assumed source terms and constant concentration production model, would reduce solute loading at the downstream receptors to below discharge limits.

A risk assessment conducted for GGM in 2012 highlighted an area of the main Geita Mine site including WD1, the NTSF, the OTSF, and the Mtakuja River as an area of highest risk owing to the potential for AMD from the waste storage facilities and their close proximity to surface water. This area is known as the Geita Triangle and was a particular focus for the 3-D seepage and solute transport investigation. The 3-D modelling of the Geita Triangle area was developed using the model Hydrogeosphere (HGS) (Brunner and Simmons, 2012).

The key outcomes from the seepage and solute transport analysis were to understand the long-term concentrations of solutes at the compliance points under various rehabilitation scenarios. An analysis of the dilution of solutes in the Mtakuja River was also completed to help inform on future diversion of water between the Nyankanga Pit and the river.

Six different solute transport scenarios were simulated with the 3-D model using the source terms shown in Table 1. Only the results of one scenario are presented in this paper: Scenario #1 used a weighted average sulfate concentration of 500 mg/L (40% PAF (960 mg/L) and 60% NAF (276 mg/L)) applied to the entire WD1 and a sulfate concentration of 588 mg/L applied to the NTSF tailings, which was considered the base case. Source terms were applied to the waste materials as constant concentration values for the full 2000-year simulation as a conservative assumption. Each solute was evaluated to determine if water quality guidelines or discharge standards were exceeded at Mtakuja River, GW29 or GW56 (groundwater compliance locations). Figure 1 shows the predicted sulfate concentration plume 100 years post-closure for (a) uncovered and (b) covered (10% NP) (b).

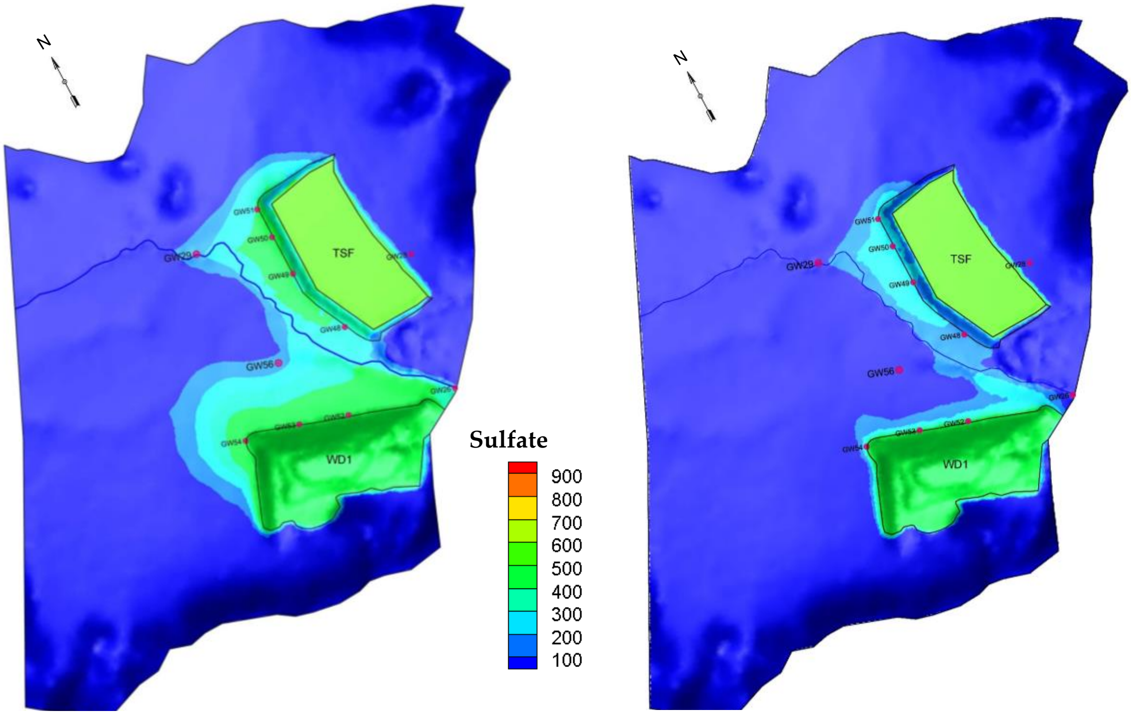

Figure 1 Predicted sulfate plume within Geita Triangle 100 years post-closure for (a) uncovered and (b) covered with net percolation of 10%. Groundwater compliance points GW29 and GW56 shown as well as Mtakuja River (surface water compliance).

Applying a cover system with an average NP rate of 10% is shown to significantly decrease the extent of the contaminant plume that develops from WD1 and the NTSF. Concentrations were predicted for the Mtakuja River based on the above model results. The mass loading predicted to report at the river included the predicted steady-state mass loading to the river from groundwater, WD1 and NTSF toe seepage, and upstream loading from the river. The Mtakuja river flow rate required to dilute loading to the river below the sulfate discharge standard (500 mg/L) for various NP rates was estimated. River concentrations were estimated for high and low river flow rates of 670 L/s and 50 L/s (based on both measured and estimated river flow rates). With high river flows (670 L/s), predicted sulfate concentrations in the river are diluted well below GGM discharge standards for all cover system scenarios. There is potential for river concentration to exceed GGM discharge standards if river flows are low (50 L/s) and cover system NP rates are 15% or higher, indicating that the cover system and landform for WD1 and NTSF should reduce net percolation to 10% or less.

Erosion and Landform Evolution Modeling

Landforms at GGM are (generally) prone to erosion, owing to the local climate, the abundance of erodible lateritic soils, the presence of relatively steep landforms and the absence of water management structures in some locations. Erosion modeling and landform evolution modeling were conducted on various slope configurations for GGM's waste facilities to evaluate if the proposed mitigation measures would result in landforms that were safe, stable, and would meet expectations for business development opportunities. The main tools and information used in these analyses included LiDAR survey of the landforms, aerial imagery (Google Earth), the SIBERIA landform evolution model, the Water Erosion Prediction Project (WEPP) model, and material laboratory analysis results. A detailed discussion of these analyses can be found in Dobchuk et al. (2013) and Kemp et al. (2014).

Based on the results of the analysis conducted for this project, recommendations were made for a cover and landform design for each of the waste rock and tailings landforms at Geita Gold Mine (GGM) using a combination of specific strategies including:

- Re-vegetation strategies (seeding etc);
- Modification of soils to include a higher proportion of coarse NAF waste rock materials;
- Provision of drainage and bunding, especially to prevent plateau overtopping;
- Resloping the tops of each bench, during dump construction, towards a hard landform (natural hillslope) to direct surface water away from the crest areas of each lift; and
- Re-shaping landforms to profiles that resist erosion (final benched landforms on the outer slope of the waste rock dump are not recommended, linear or concave landforms are preferable).

DISCUSSION AND CONCLUSIONS

The project described in this paper was initiated to develop mitigation methods for the waste rock and tailings storage facilities at Geita Gold Mine (GGM) that would result in GGM meeting or exceeding their stated reclamation objectives including the creation of stable landforms and the reduction of solute loading from the waste storage facilities to meet discharge standards at the downstream compliance points. The conceptual model was that a cover system and landform design using the locally-available laterite material would reduce net percolation to a moderate level (10-15% of mean annual rainfall) and that this would be sufficient to reduce the solute loading at the downstream receptors to below discharge standards. This design was verified based on the results of the material characterization, the surface and groundwater quality assessment, and various numerical modeling analyses.

Based on the site visit and the results of the surface and groundwater quality assessment, it was determined that the PAF waste encapsulation as part of the GGM waste management plan was acting to reduce exposure of the PAF waste to oxygen and water and was leading to a reduced contaminant load to downstream receptors (versus non-encapsulated waste). The placement methodology, with trafficked layers of laterite material on top of each lift and the paddock-dumped base and PAF layers was likely acting to reduce the vertical infiltration of water and the advective movement of oxygen through the waste rock via preferential flow paths. Thus, with a lower potential contaminant load within the waste facility, a cover system with only low to moderate reduction in net percolation (NP of 10-15%) was shown to be sufficient in reducing the solute concentrations at downstream receptors to below discharge limits. The cover system and landform design that met these requirements was also shown to be feasible using the locally-available laterite materials with only slight improvements to the landform design to increase stability—leading to rehabilitation options that were cost effective.

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