Groundwater Management Planning at an East African Gold Mine

by
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Development of the mining operations at the Geita Gold Mine (Tanzania) was largely based on a surface water supply system based on a small offline dam and pumping from Lake Victoria. Apart from some low yielding construction water supply bores and the installation of a baseline groundwater quality monitoring network, there was only minor investigation of groundwater resources during project development.

Post commissioning due diligence auditing prior to completion of project financing, included a review of baseline monitoring data and the initial mine inflows, and identified the need for an integrated mine water management plan. An internal Geita environmental review identified the need for focussed investigation of groundwater resources and formed the basis of a structured groundwater management plan (as a critical component of the overall mine water management plan).

Initial investigations were directed at developing a conceptual hydrogeological model of the mine area and developing specific site programs to test/confirm the conceptual model and to provide area specific aquifer parameters. Groundwater flow regimes were identified and used to determine the environmental risks posed by potential seepage from the tailings dam, waste rock dumps and other mine infrastructure; and the risks to mining from groundwater inflows and/or pit wall hydrostatic pressures. Preliminary environmental and mining groundwater management plans were then developed and implemented. To assist in the collation and storage of performance monitoring data, tracking of performance against targets and in quantifying the mine water balance, a site specific database and water balance model (Geita - Aquascape) was developed.

This paper presents an outline of the development of groundwater management plans at Geita, where they fit with overall mine water management and environmental planning, the development of the Geita - Aquascape database, and where mine water management systems developed at Geita can be applied elsewhere.

1 INTRODUCTION

The Geita Gold Mine (GGM), jointly owned by Ashanti Goldfields and AngloGold, is located approximately 4km west of the town of Geita in the Mwanza Region of Tanzania (refer Figure 1). The initial open pit mining operation, Nyankanga Pit, and the GGM processing plant facilities are located within the catchment of, and near the headwaters of, the Mtakuja River which drains into Lake Victoria at Nungwe Bay approximately 20km to the northwest. Mining at Nyankanga commenced in 1998 and processing of ore in 1999.

As part of GGM’s mine development programme, investigations were carried out to determine baseline hydrological/hydrogeological conditions, to assess groundwater supply potential and to assess pit dewatering requirements. One key consequence of the results of the earlier investigations was the development of a surface water supply scheme to sustain all mine, plant and camp water requirements. This scheme pumps water from Nungwe Bay to the mine via a dedicated pipeline to Nyankanga Dam, a small diversion dam located upstream of the Nyankanga Pit.

Post commissioning due diligence auditing by the project financers included a review of environmental baseline monitoring data and operational water management data and identified the need for an integrated mine water management plan. Internal GGM audits and the development of an ISO14001 Environmental Management System also identified the need for additional hydrogeological investigations to provide a better understanding of the overall hydrogeology of the area, the implications for mining and the potential impacts of mining on downstream water resources.

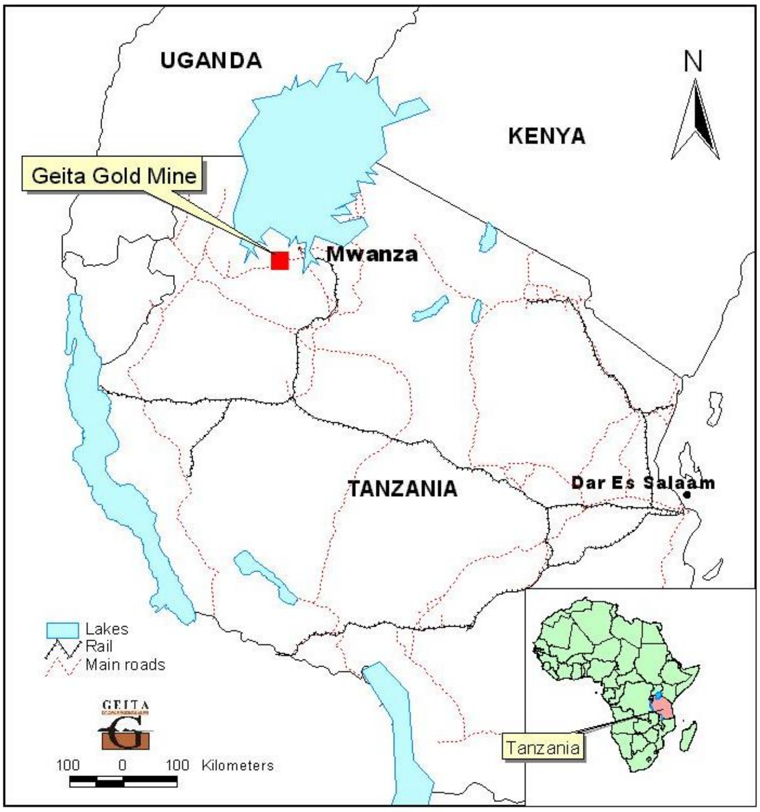

Figure 1 Site Location

2 CONCEPTUAL HYDROGEOLOGICAL MODEL

The assessment of local/regional hydrogeological conditions and the development of the conceptual hydrogeological model was based on observations by Aquaterra during four site visits, the results of ongoing drilling and hydraulic testing, discussions with mine personnel and review of previous work done in the area.

2.1 Geology and Topography

GGM is located within the Geita Greenstone Belt, an east-west trending Archean aged feature comprising isoclinally folded BIF and younger felsic volcanoclastics, which have been intruded by microdiorites. These have been deformed to form west-plunging folds, which have subsequently been displaced along major northwest trending faults and shears, and intruded by a series of northeast trending porphyry dykes.

The landscape is dominated by prominent ridges of BIF with some intervening shallow valleys and plateaux. The basement rocks have been deeply weathered to form variably thick sections of saprolite and saprock, depending on the basement rock type. In places the saprolite can be relatively thin (eg. over BIF), but the base of the saprock can be up to 100m below surface in places.

Ferruginous colluvial material has been deposited over much of the lower hills slopes and valley floors. These deposits, locally known as "transported ferricrete", can range in thickness from several metres on hill slopes to over 50m in the buried valleys of ancient and current water courses. The upper sections of this unit have been variably cemented (ferruginous cement) to form hard, semi-continuous, surface duricrust layers, locally known as "hardpan ferricrete".

The hardpan ferricrete forms prominent plateaux and bench-like areas that are characterised by the general lack of large trees and low "football mound" termite nests (as a result of the relatively inpenetratable nature of the hardpan).

The colluvium and weathered basement have been incised by present day drainage channels. These are characterised by floodplain deposits (silts, sands and minor gravels) and vegetation in the main river channel areas (eg Mtakuja River) and by higher energy deposits (sands and gravels) in the upland drainage courses.

The local/regional hydrogeology is strongly influenced by the local geology and regolith types. That is, the distribution of rainfall runoff, groundwater recharge, groundwater movement, groundwater emergents and baseflow to rivers is controlled by the distribution of regolith types.

Figure 2 shows a plan of the main GGM lease areas showing the distribution of the four main physiographic units that influence the hydrogeology, together with regional monitoring bores. Each of these four units represents a combination of individual regolith units identified as part of a regional regolith mapping exercise (Regolex, 2001).

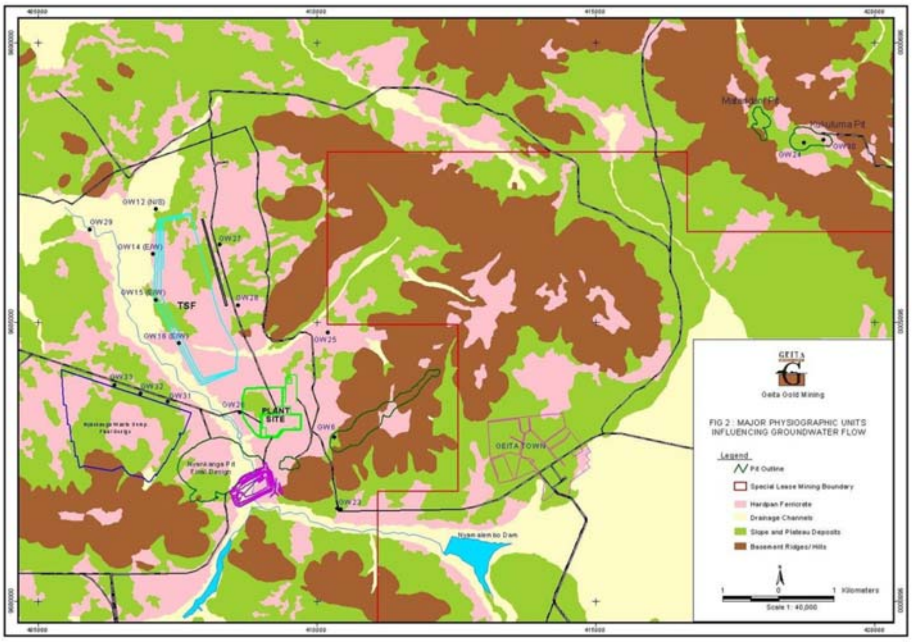

Figure 2 Main Physiographic Units

2.2 Climate and Drainage

The GGM area has a highland equatorial wet-dry weather pattern with a bimodal wet season and an average annual rainfall of around 980mm. The wet season generally extends from October/November to April/May, with the wetter months being November and April.

Rainfall runoff from the upland ridge and hardpan ferricrete areas is very high and generates rapid response streamflow (and sheetflow over hardpan areas). Runoff from other upland and slope areas is dependent on rainfall intensity compared to the infiltration capacity of the surface soils and soil moisture deficit. In light to moderate intensity rainfall events, much of the rainfall will infiltrate through the transported material and saprolites/saprocks to the local groundwater tables.

2.3 Aquifers and Aquicludes

Several aquifer types have developed in the Geita area as a result of both primary hydraulic properties (ie permeability and porosity) of recent colluvial and alluvial deposits, and secondary hydraulic properties (structural and weathering induced) of the basement rocks. The main aquifers present are as follows:

- ***Shallow Aquifer:*** shallow, unconfined (and sometimes perched) aquifer within the river channel alluvium and valley slope and plateaux colluvial deposits (transported ferricrete). Aquifer potential is associated with primary granular permeability and porosity in the alluvium/colluvium.
- ***Deep Aquifer:*** shallow to deep aquifer within the basement rock profile, including the saprolite and saprock horizons and deeper unweathered rock. Aquifer potential in the saprolite/saprock horizons is associated with secondary, weathering induced permeability and porosity, which is particularly pronounced along zones of relic basement structure (faults, shears, quartz veins etc). In the unweathered rock, aquifer potential is associated with secondary, structural induced permeability and porosity. The Deep Aquifer can be unconfined, where the Shallow Aquifer is absent, dry or perched, and semi-confined to confined elsewhere. The saprolite tends to be less permeable than the other horizons and generally acts as an aquitard/aquiclude between the Shallow Aquifer and the saprock and rock of the Deep Aquifer.

The ranges of measured hydraulic conductivities from field tests are summarised in Table 1.

Table 1: Range of Hydraulic Conductivity Values

Aquifer	Unit	Estimated Permeability (m/d)	Comments
Shallow	Transported Ferricrete	0.01 to 5	Packer & falling head tests
Deep	Saprolite	0.001 to 0.1	Packer & falling head tests

	Saprock and Fractured Basement (Nyankanga)	0.01 - 1	Packer & falling head tests
	Saprock and Fractured Basement (Kukuluma)	N/A	Airlift yields of around 8 to 10l/s in fractured BIF and felsics.
	General Basement Rock	0.0001 to 0.1	Packer, airlift recovery & rising head tests

2.4 Local Groundwater Recharge, Flow and Discharge

Figure 3 shows a schematic hydrogeological section through a typical slice of the GGM site.

Recharge to the groundwater is by infiltration of rainfall and runoff through the near surface horizons to the Shallow Aquifer, and thence by vertical flow to the Deep Aquifer. As discussed above, the regolith type is the principal control on recharge.

The water table surface is a subdued reflection of topography and groundwater generally flows from the highland areas towards the lowland valleys and river floodplains. Some of this flow is via deep groundwater flow pathways, and some via shallow, near surface pathways.

Natural groundwater discharge is via spring flow at groundwater emergents or baseflow to streams and rivers. Groundwater emergents (or springs) occur where the water table intersects the land surface, where the change in topographic slope exceeds the gradient on the water table. This mostly occurs towards the top of steep hill slopes and at sharp erosional breakaways. Emergent groundwater flow generally occurs via horizontal flow paths.

Groundwater baseflow occurs lower down on hill slopes and within the main valleys, where the general land surface becomes lower than the regional water table or potentiometric surface. Groundwater baseflow generally occurs via horizontal or upward flow paths.

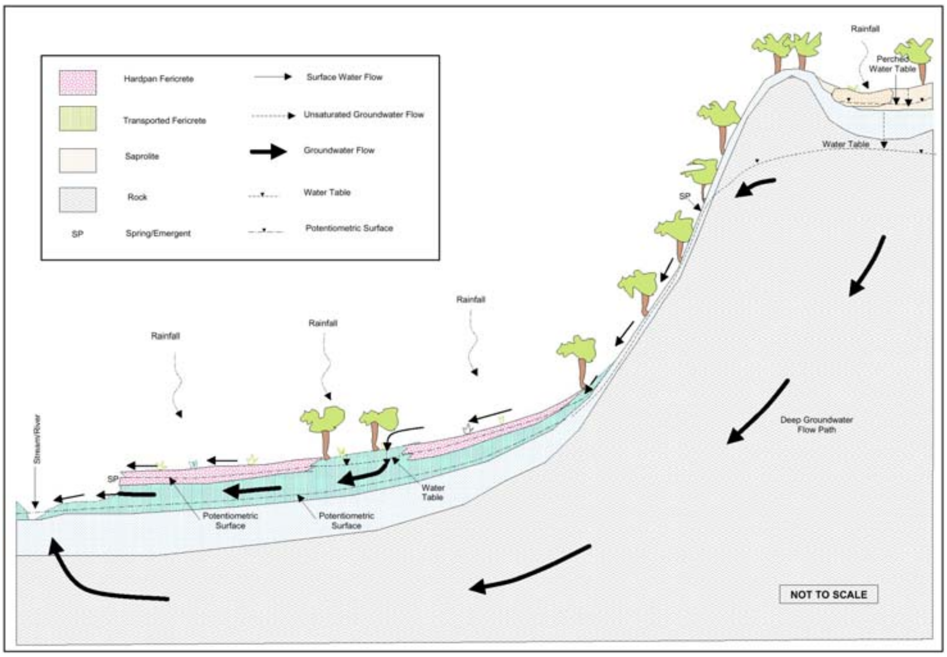

Figure 3 Hydrogeological Cross Section

Groundwater in the Deep Aquifer is generally "older" than that in the Shallow Aquifers. This is reflected in groundwater chemistry monitoring data, which generally show higher salinity (TDS) in the deep monitor bores. Flow into and within the Deep Aquifers involves longer travel paths and travel times between initial rainfall recharge and discharge (or interception by monitor bores). The longer travel times allow for more "leaching" of minerals from the aquifer matrix.

3 APPLICATION OF CONCEPTUAL MODEL

The key issues in relation to the influence of local hydrogeological conditions on mining operations and the impacts of mining operations on the local and regional hydrogeology are as follows:

- The need for and design of pit (and possible future underground) mine inflow control (dewatering) measures.
- The impacts of mine water management systems on groundwater flows and surface water flows.

- The impacts of current mine operations on downstream water quality as distinct from the impacts of historical mining and current mining (artisanal) by others.

3.1 Mine Dewatering

Figure 4 shows a slice of the conceptual hydrogeological model through the Nyankanga Pit area. This shows groundwater flows towards the pit through both the Shallow and Deep Aquifers, and the influence of seepage from the Nyankanga Dam through the WD5 waste dump.

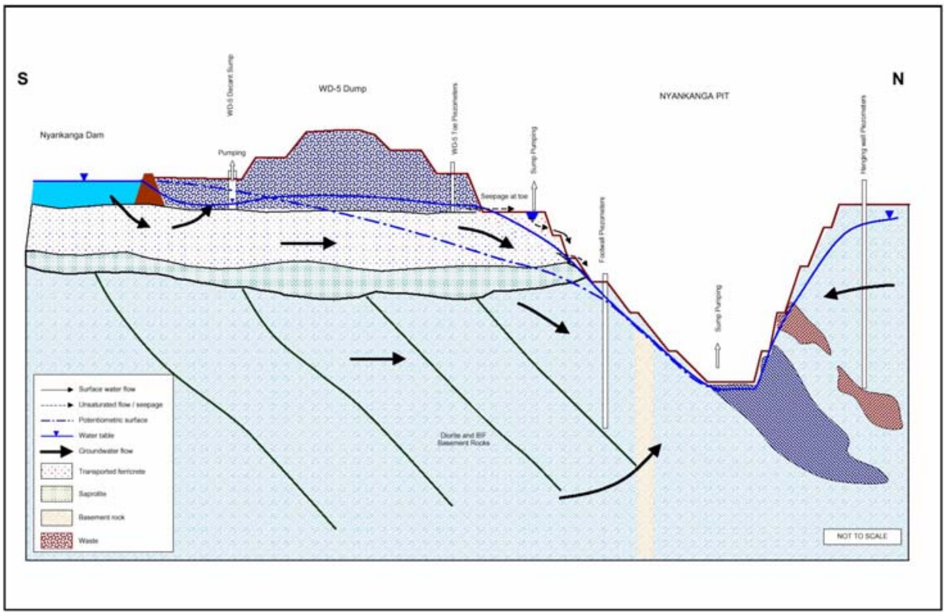

Figure 4 Section Through Nyankanga Pit

As part of ongoing investigations, simple hydraulic testing was carried out by mine personnel on selected boreholes. A simple lumped parameter analytical groundwater flow model was used to provide estimates of potential mine inflows. The model was based on the measured hydraulic conductivity values and "typical" values of other input parameters and was calibrated against observed inflows and then run to predict future inflows to the open pits as they expanded and deepened.

It was recognised that the predictions covered inflows derived from the Deep Aquifer and assumed that the Shallow Aquifer had been largely drained. However it was also recognised that the expanding pit would intersect additional transported material, that may not have drained and that re-wetting of previously drained material might occur during and after flood events. This had implications for geotechnical stability of the shallow pit walls and prompted installation of an expanded grid of monitor bores to confirm water table conditions ahead of mining.

Where airlift tests in exploration boreholes demonstrated significant yields (eg at Kukuluma), advance dewatering using boreholes was considered; and where appropriate planned. Airlift testing of mineral exploration and geotechnical bores is now a normal part of ongoing mine investigations. The results have been used together with preliminary mine plans and simple analytical flow models to assess potential mine inflows. In all but one case to date, the results have indicated that inflows will be relatively minor and that there should be no significant mine water management issues. In one case (Geita Hill), where an open pit is currently being developed in an area of previous underground mining, it was recognised that there may be some water quality issues associated with the pumping out of accumulated water in the old underground workings so hydrochemical investigations were initiated.

3.2 Impacts of Mining on Water Flows

There are surface water diversion schemes around the plant, TSF and waste dump. However, these merely re-direct surface flows around mine infrastructure rather than intercept or interrupt downstream flow. They also have little impact on overall groundwater flow, other than reducing potential recharge in some areas but increasing it in others due to modified surface water flow paths.

The main net impacts on groundwater and surface water flows in the main Geita mining area are as a result of the Nyankanga Dam and the open pits. The Nyankanga Dam captures surface water flow in the Mtakuja River valley upstream of the Nyankanga Pit. Thus, surface water flow is interrupted except when the Dam overtops and discharges downstream via a diversion channel. However, the Dam also results in deep, ponded water over the transported ferricrete and this increases recharge to the shallow and deep aquifers. The mounding is partially offset by the “cone of depression” in the water table around the mine which has developed as a result of pit inflows. Based on results to date it is expected that significant drawdowns could extend for some distance (perhaps up to a kilometre or so) from the pit.

Post mining, the impacts on groundwater and surface water flows from decommissioned mine infrastructure will remain largely the same as is now, although there may be more localised recharge to groundwater in the de-constructed plant area. The main impacts will be as a result of Nyankanga Dam and the final mine voids. It is assumed that Nyankanga Dam will remain in place as a local public amenity and that the minor impacts on surface water flow will be acceptable to the community.

The mine voids could continue to act as groundwater sinks. Assuming that the pits are not backfilled at the completion of mining, pit lakes will form as groundwater inflows continue after dewatering systems are decommissioned.

The level to which the pit water levels will rise and the degree to which this will impact on local groundwater and surface water flows will depend on aquifer parameters and recharge rates and the size of the pits. At Nyankanga, where aquifer permeability is low and the final pit has a large area, the pit is expected to become a groundwater sink. That is, the steady state pit water level will be well below the pre-mining water table and the pit will intercept all groundwater flows in the area surrounding the pit. At Kukuluma, where the pit is smaller and the permeability is higher, the final void may only become a partial sink (or partial throughflow pit). That is, the steady state pit water level will still be depressed below the pre-mining water table level, but there will remain some water outflow from the down gradient end of the pit. In both cases, the impacts on regional groundwater (and surface water) flows would be less than during mining.

3.3 Impacts of Mining on Downstream Water Quality

The main potential impacts of existing and planned mine development on future downstream groundwater (and ultimately surface water) quality are related to:

- Waste Dumps – potential for generation of acidic leachate with elevated metals concentrations.
- Final Mine Voids – potential for migration of saline and/or acidic water from final pit lakes.
- TSF – potential for seepage of tailings liquors with elevated cyanide and other process chemicals.
- Old Mine Workings and Tailings Pile – potential leachates generated by the oxidation of sulphides.

- Artisanal Workings – potential sources of low pH high iron and high mercury seepage.

A simple Darcy flow model was used to predict seepage velocities and travel times, based on measured (or assumed hydraulic gradients), derived permeabilities and assumed effective porosities. It was found that, apart from the final voids, there was very little difference in average hydraulic gradients downstream of the various contaminant sources. The following average seepage velocities were derived:

- Shallow Aquifer – around 0.2m/d
- Deep Aquifer – less than 0.01m/d

For all identified sources other than the final pit voids, the following travel times to the nearest surface water discharge zone were estimated for the Shallow Aquifer:

- Nyankanga Waste Dump (WD1) to Mtakuja River – 1,000 days
- TSF to Mtakuja River – 500 days
- Old Mine Workings and Tailings Pile – in excess of 1,000 days
- Artisanal Workings – in excess of 1,000 days

It should be noted that the design of the TSF incorporated under drainage and seepage collection measures, and monitoring to date does not indicate the presence of any seepage. Also, the waste dumps have been designed to minimise the potential for leachate generation. This exercise was carried out to determine travel times in the event that any seepage did bypass the systems in place.

It was concluded that most, if not all, of any contaminants would remain within the more permeable Shallow Aquifer. However, it was recognised that some seepage through the Deep Aquifer could occur where there were downward hydraulic gradients. Average travel times within the Deep Aquifer were estimated to be at least twenty times longer than in the Shallow Aquifer.

Evaporation losses from the open water surfaces of pit lakes will result in salinity increases. The degrees and rates of salinity increase, and the potential for downstream migration of saline water, will be controlled by the relative differences between groundwater inflow (and outflow) rates and evaporation losses.

At Nyankanga, which is expected to become a groundwater sink, there will be no outflow of water from the pit (at least not in the initial stages) and thus no impact on groundwater quality outside the pit. Over the very long term, there may develop significant density difference between the saline pit water and underlying groundwater and there could be vertical density driven flow from the base of the pit. However, the plume of dense saline water will tend to sink within the aquifer, displacing fresher, less dense groundwater upwards, until such time as the saline water plume meets an impermeable barrier at which time it will tend to move down slope, although it is unlikely to appear in the local or regional Sallow Aquifers (that might be developed for village wells etc) or as base flow to streams and rivers.

At Kukuluma, where the pit may become a partial sink (ie partial throughflow pit), there may be some, if only minor, outflow of saline water. The degree to which this will impact downstream water quality will depend on the relative magnitudes of groundwater outflow from the pit and groundwater throughflow in the receiving aquifer, and the relative differences in water quality of the two water flows. It is likely though, that dilution will reduce salinity such that regional groundwater quality and surface water quality will remain unaffected, although there could be locally observable impacts.

4 GROUNDWATER MANAGEMENT PLAN

The previous sections covered the conceptual hydrogeological model of the Geita Mine area and the predicted broad impacts of local hydrogeology on existing and future mining operations, and the broad impacts of mining on local and regional hydrogeology. In some cases sufficient hydrogeological investigation has allowed for quantitative predictions. In other cases, qualitative/indicative predictions have been made on the basis of available geological information and comparison with “better known” areas. In all cases, however, the reliability of predictions and the plans developed to manage hydrogeological issues can be, and need to be, improved with ongoing investigation, monitoring, verification and revised prediction (where necessary).

A mining specific Groundwater Management Plan was developed to address hydrogeological issues over the following five years. This plan included:

- Identification of specific key issues at specific pits and at specific times.
- Planned objectives/tasks to address these key issues, including further investigation, monitoring and revised prediction.

- A schedule to complete the objectives/tasks over the next five years.

The Groundwater Management Plan was developed as a "working document" and was designed to be updated/revised on an ongoing basis as results of progressive investigations and monitoring come to hand, and mine plans are revised/refined.

Key components of the Groundwater Management Plan are:

- Broad description/discussion of the overall hydrogeological issues that need to be addressed.
- Tabulated listing of the specific issues with specific action plans and schedules, including performance review. This listing also forms part of a mining issues register on site, and includes tracking of progress on issues.
- Maps/plans of existing and future operations showing the locations and schedules of specific action items (eg new test bores, monitor bores and other monitoring systems, and dewatering bores).
- A summary Gantt chart showing the schedule of action items.
- A schedule of quantities for the drilling and installation of new bores.
- A summary listing of ongoing groundwater monitoring requirements.
- An outline of the on-site and off-site resources that GGM will need to implement and develop/evolve the Groundwater Management Plan.

The actual Groundwater Management Plan is a lengthy document (Aquaterra, 2002) and covers over forty specific issues and action plans that are currently being, or are scheduled to soon be, implemented. As a result of changes to mine plans or the outcomes of other actions plans, some issues are no longer relevant and have also been removed from the Register. In some cases the outcomes of one (or more) action plans have identified new or modified issues.

As an example, the specific hydrogeological issues identified included:

- Mine (pit) specific issues: such as the need for dewatering sumps or bores at specific locations, the need for better management of surface water runoff around the pit, the need for new or replacement monitor bores, etc.
- General issues: such as the need for structured monitoring and testing programmes, clear data presentation formats, resource and training requirements.

A summary Gantt chart showing the schedule of action items; schedules of quantities for the drilling; and installation of new bores; and summary tables listing ongoing groundwater monitoring requirements are also included as an important part of the plan.

5 GROUNDWATER MANAGEMENT PLAN DATABASE

One of the early action items in the Groundwater Management Plan was the development of clear data presentation formats using the existing Excel spreadsheet system used to record monitoring data. Key data plots included:

- Plots of historical water levels in pit floor, pit wall and pit crest piezometers versus actual and projected pit base. This allowed for simple visual extrapolation of target versus planned water levels by Mine Management.
- Plots of monitoring data versus compliance levels, to allow for simple visual assessment of compliance with statutory and internal limits (eg water quality parameters).

However, as the volume of data grew and the various different forms of data recording expanded, it became clear that a spreadsheet would not be capable of providing a user friendly “one stop shop” to store, retrieve and plot/present all the data being generated by the Groundwater Management Plan.

It was decided to establish a site specific database, using the Aquascape database-water balance model system.

Aquascape is an environmental database and water management system designed for mining operations. Aquascape uses Microsoft Access, and is designed for simple configuration to the specific requirements of any mine facility, and provides a central repository for environmental and water related data. The database is designed with a tree-based structure, like Windows Explorer, which allows elements to be added or deleted very simply, or to be displayed in expanded or collapsed mode to provide the required level of detail.

Aquascape was initially established on the mine in 2003 as a trial, focussing on water monitoring data for Nyankanga Pit. Monitoring information was input as raw field data, and the database provided the following automated key data plots:

- Total pit inflows versus time and pit depth.

- Total seepage recovery downstream of Nyankanga Dam (from sump bores within the WD5 waste dump and a seepage recovery trench at the toe of the dump) versus Dam water level.
- Water levels in piezometers located at the footwall crest and within the footwall of the pit versus water levels in the Dam.
- Water levels in piezometers within and around the pit versus the elevation of the pit base.

All field testing data (airlift tests), borelogs and previous hydrogeological reports were also stored in the database with easy to follow retrieval procedures.

The system is currently been upgraded to:

- Accommodate water monitoring data from all mining operations.
- Include a water balance model for each mining operation.
- Include all monitoring data and compliance information for the HSE Department.

6 RESOURCE REQUIREMENTS AND KNOWLEDGE TRANSFER

The development of the Groundwater Management Plan demonstrated the need for a clear "driver" of the work programmes required by the Plan. The driver is responsible for:

- Scheduling the work, and prioritising individual work programmes if/when there are timing/resources conflicts.
- Ensuring that GGM and contractor resources are available to meet the schedules.
- Ensuring that monitoring and testing is carried out as recommended.
- Ongoing site review of data and forwarding of data summaries to external consultants for external review and analysis.
- Ongoing liaison with external consultants and planning/implementation of site visits and other scopes of work that may become necessary.

It was also recognised that the management plan could be used as the basis of a "knowledge transfer" protocol. During site visits by the consultants, knowledge transfer and training sessions have been held with technical support staff on the mine. These sessions have covered the following:

- General hydrogeological concepts as they relate to groundwater flows and groundwater-surface water interaction at Geita, leading up to the overall conceptual hydrogeological model for the site.
- Use of the conceptual hydrogeological model to understand and predict the potential impacts of mining operations on groundwater and surface water flows.
- The reasons for, and importance of, monitoring and use of the conceptual hydrogeological model to develop sound monitoring programmes (in terms of where to monitor and what to monitor for).
- Alternative sampling methodologies and available equipment.
- Hydraulic testing procedures (falling and rising head tests) and data recording formats.
- Use of the Aquascape database and water balance model.

The knowledge transfer has been critical in maintaining support for the management system and has allowed the need for continued external hydrogeological review and planning site visits to be limited to a six to eight monthly schedule for visits by a hydrogeological consultant. The level of on site knowledge and the dedicated database, that can be transferred by e-mail means that that any detailed assessment (eg groundwater modelling) and/or design can be carried out off site.

7 CONCLUSIONS

This case study has demonstrated that even in a complex mining and hydrogeological situation, a well planned investigation strategy, together with an appropriate data gathering and management plan can provide important and valuable information for an overall mine Environmental Management System (EMS). The knowledge transfer required to implement and manage the plan greatly reduces the on site time required from external consultants, while a dedicated database allows easy transfer of information and efficient detailed analysis.

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REFERENCES

Aquaterra, 2001. Hydrogeology and Groundwater Management. Report to Geita Gold Mine Limited, December 2001.

Aquaterra, 2002. *Groundwater Management Plan for Mining Operations.* Report to Geita Gold Mine Limited, November 2002.

Geita Gold Mining Limited, 2001. *Annual Environmental Report 2000.* Report to the government of the Republic of Tanzanian, January 2001.

George, Orr and Associates, 2000. *Geita Gold Mine: Nyankanga Pit: Report on Site Visit held between 28 January and 02 February 2000.* Report to Ashanti Goldfields (Tanzania) Ltd, March 2000.

George, Orr and Associates, 2000. *Geita Gold Mine: Nyankanga Pit: Report on Site Visit held between 14 and 20 August 2000.* Report to Ashanti Goldfields (Tanzania) Ltd, October 2000.

George, Orr and Associates, 2000. *Geita Gold Mine: Nyankanga Deposit: Interim Report on Rock Quality and Rock Mass Defect Orientations Measured from Exploration Borehole Cores.* Report to Ashanti Goldfields (Tanzania) Ltd, March 2000.

Kevin Morgan and Associates, 1999. *Groundwater Investigation Geita Project Tanzania..* Report to Ashanti Goldfields Company Limited, March 1999.

Kevin Morgan and Associates, 1999. *General Hydrogeology Kukuluma Hill.* Report to Ashanti Goldfields Company Limited, March 1999.

Knight Piesold Consulting, 1999. Geita Gold Mine Project. Tailings Storage Facility and Nyankanga Diversion Works Design Report. Report to Lycopodium Pty Limited, July 1999.

Regolex Pty Ltd, 2001. Landform and Regolith Map Geita District Tanzania. Prepared for AngloGold Africa Region Exploration and Ashanti Goldfields (Tanzania) Ltd.