MINE WATER MANAGEMENT IN MODERN AFRICAN MINING OPERATIONS

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ABSTRACT

Water is essential to metal mining operations. Properly operated water management systems must ensure adequate capacity to make up water shortfalls under dry conditions and absorb surplus under wet conditions. In addition, the control of mine contact water and minimizing/eliminating unwanted mine water discharges are often the core tasks for production needs and mine site environmental management.

Real-life mine site water management systems may substantially differ from those initially planned during mine development due to variations of mine plan, tailings and waste rock characteristics and mine process contact water qualities. To adapt to the above changes, mine operators need to modify the physical structures or operational rules of the water management systems. The ability to properly operate/modify the water management system is just as important as the design. To meet today's stringent environmental regulations, there is often little or no room for error. Modern mining operations need the capability to predict the dynamic and probabilistic behaviours of their water management systems. This ability relies on proper understanding of system feedbacks with local hydrologic conditions and the capability for proactive management action to sustain normal operation.

This paper presents the water management systems that have been utilized in two Barrick mines in Tanzania.

1. INTRODUCTION

Mine site water management systems are designed to transfer and contain process water, contact water, and freshwater. The effectiveness of these systems is not only determined by sound technical design (hydrology, hydrogeology, hydraulics, metallurgy etc.) but also through proper operation and modification by operators. Water management systems are likely to evolve over different mine operational stages.

Operational conditions often deviate from those anticipated during design stage, due to numerous inherent uncertainties such as possible overestimation/underestimation of site rainfall and pond evaporation due to lack of meteorological record in the design phase; variation of process water reclaim rates caused by unpredictable long-term mine waste behaviour; and changes in water consumption due to modification of the mine plan. Identifying the causes of these deviations is the first step for the mine operators to modify the system and establish a new operational norm. As the water management system can be quite complex, water balance modeling, which links water sources, sinks and facility storages, is often needed to aid this decision-making process.

This paper describes such processes at Barrick's Bulyanhulu Gold Mine (BGM) and North Mara Gold Mine (NMM) in Tanzania (Figure 1). Detailed water balance model development and application were published separately (Lin Shelp et al., 2009).

In Eastern Africa, where the two mine sites are located, a sharp division between wet and dry seasons is the dominant climatic factor that shapes the annual life cycle of society as well as mine water management. Variations in the length, timing and intensity of the two seasons can have profound impacts on mine water supply, storm water management and contact water containment. Water management designs for this type of climate must have the flexibility to provide sufficient water supply during prolonged dry season and absorb extreme flood conditions in the wet season. The effectiveness of any modification to the water management system must be evaluated for both wet and dry conditions.

Figure 1. Location of the Bulyanhulu Gold Mine and the North Mara Gold Mine

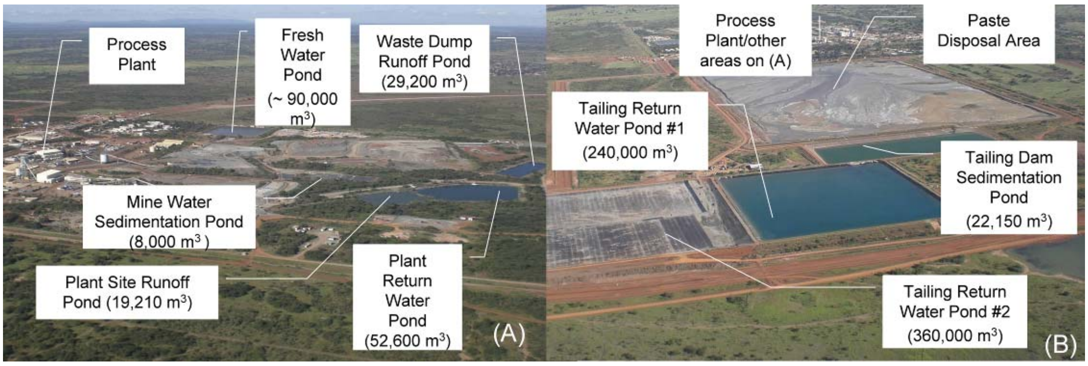
2. BULYANHULU GOLD MINE

Site Description

BGM is located approximately 55 km south of Lake Victoria. It lies on a flat plain occupying approximately 50 km^2 of land. On average, the area receives annual rainfall of about 950 mm/year with a much higher potential evaporation (PE) of 1,700 mm/year. Most of the rainfall is concentrated within a wet season (November through May).

BGM consists of an underground mine, a mineral processing plant and a surface paste tailings storage facility. Average ore processing rate at BGM is about 2,300t/day. Approximately 82% of the process water can be circulated within the processing circuit with remaining make-up water of 900 m^3/day. A pipeline brings fresh water from Lake Victoria to supply potable and process water to the mine.

BGM has a complex water management system that is able to transport water among seven contact/process water storage ponds (Photograph 1), depending on daily water quality and quantity in each facility. With the newly commissioned Return Water Pond #2, the capacity within the two return water ponds (600,000 m^3) represents 83% of the total on-site storage capacity.



Photograph 1. Layout of key water management facilities at the Bulyanhulu Gold Mine.

The water management mandate at BGM is to maintain acceptable water quality in the facilities and eliminate discharge during upset conditions. Since mine dewatering from the underground workings and the supplemental water supply from Lake Victoria are fairly reliable sources, water supply in the dry season is generally not a concern.

Management of the Evolving Water Management System

The original design of the water management system at BGM called for regular discharge of clean effluent to the environment. With the change of government regulation, the mine was required to operate as a zero discharge facility beginning in 2002. By then, surplus water had accumulated in the system, nearly reaching the full storage capacity in each facility. BGM retained two consulting firms to inspect the pressing situation and followed their recommendations to add a new water storage facility (Return Water Pond #2) that has doubled the site water storage capacity from about 360,000 m^3 to 720,000 m^3. Water in the storage facilities is grouped as contact water (all runoff within the site boundary and process water) and fresh water (water from Lake Victoria). Since water is regularly blended among the seven contact water ponds to ensure acceptable water quality to be used in the process plant, the water balance model simply reflect this day-to-day operation by treating the seven contact water ponds as one pond.

To understand the behaviour of the new system, a monitoring program was put in place to measure pond levels weekly and selected key flows daily. A water balance model was also developed to track the daily inflows, outflows and estimated pond volumes. The model was built within the GoldSim® simulation environment with linkages to MS-Excel for data input and output. The accuracy of the model is continuously checked by comparing the modeled total pond volume with any new observation data. If the modeled pond volume matches the observed value, then the model is used to project short-term and long-term pond volumes in a probabilistic manner.

With the additional storage capacity, pond volumes have been within the designed operational conditions for over two years (April 2007 to June 2009). Results of the water balance analysis (Figure 2) show the comparison of modelled and observed data for the period between January 1, 2007 and June 3, 2009, and project the total site water inventory for the following 24 months between June 2009 and May 2011. Results indicate that the site is still experiencing a slight water surplus, likely resulting in a gradual increase in total site water storage. Detailed analysis of the data has helped the mine to identify several flows that have changed over time. Among them, the most significant deviation is the increased inflow from the underground mine dewatering, from an estimated 10 m^3/day in 2002 to 1,000 m^3/day currently.

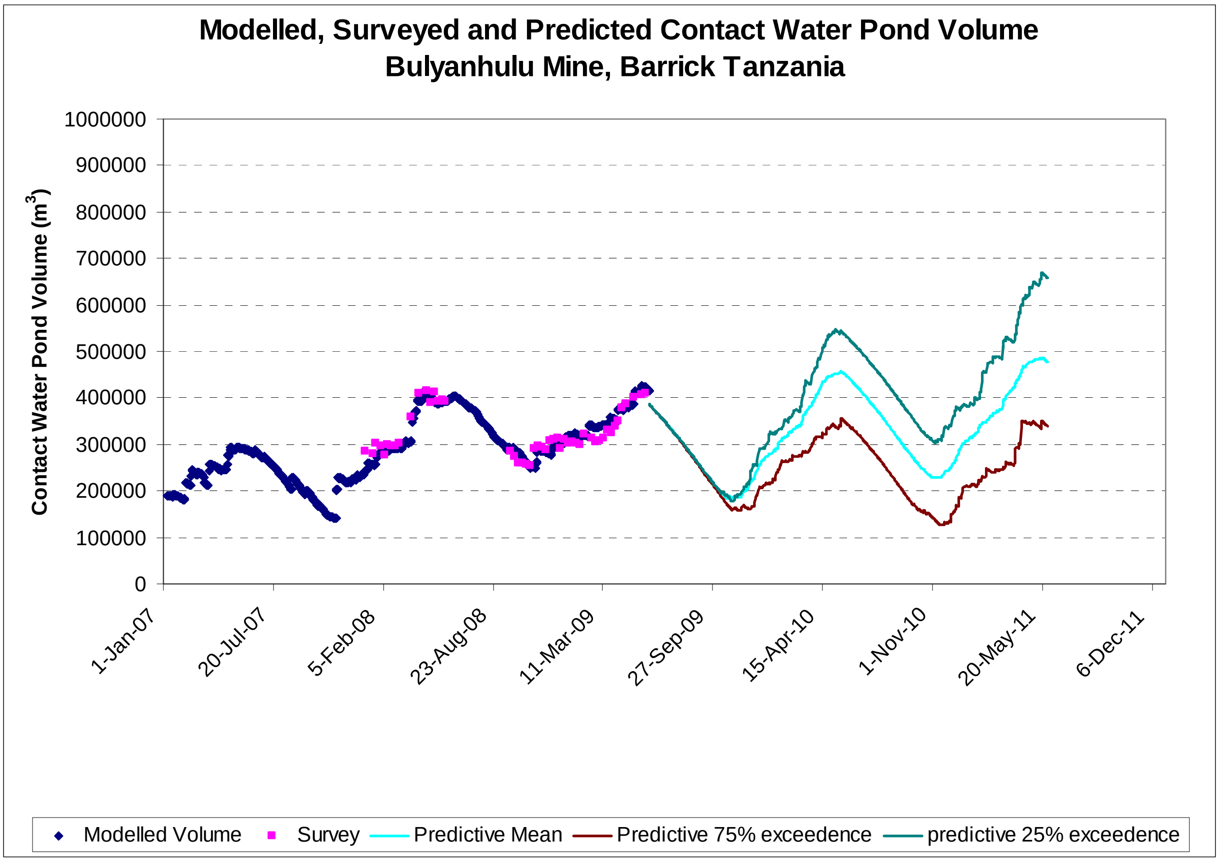


Figure 2. Results of water balance analysis at the Bulyanhulu Gold Mine

The early detection of possible surplus has give BGM the ability to seek sustainable solutions to maintain site water balance. Currently, BGM is investigating the effectiveness of forced evaporation techniques to reduce the net inflow.

A clear understanding of the site water balance has also guided the design of a water supply and discharge system for a new refrigeration plant which will generate an effluence from the cooling tower. Based on predictive analysis using the water balance model, the existing site storage will not able to contain the additional flow for more than one year. Management concluded that the proposed refrigeration plant needs a stand-alone water management and treatment system, and will possibly require recycling of the bleed water.

3. NORTH MARA GOLD MINE

Site Description

The North Mara Mine (NMM) is located approximately 100 km east of Lake Victoria and 20 km south of the Kenyan border (Figure 1). It is situated in the northwest highlands and the isolated Granitic Mountain region of Tanzania. The topography of the mine and surrounding area is characterised by occasional hills among flat grass and farmlands with slopes ranging from 1% to 15%.

NMM consists of three open-pit deposits – Nyabirama (Rama), Gokona and Nyabigena (Gena). The Gokona and the Gena deposits are close by, whereas the Rama deposit is approximately 10 km to the southwest. The total annual milling rate is 2.8 million tonnes (or 7,700t/day). The gold extraction process includes a gravity separation circuit, cyanidation and carbon-in-leach recovery followed by electrowining and gold refining.

On average, the area receives annual precipitation of 1,280 mm/year, with a similar magnitude of potential evaporation. The current process water demand is approximately 9,000 m^3/d, of which about 5,000 m^3/d is circulated within the plant and the remaining 4,000 m^3/d must be supplied from external sources. There are three main external sources of process water supply: (1) raw water from the Raw Water Dam, which stores site runoff, (2) water abstraction from the Mara River and (3) reclaimed water from the Tailings Dam. The mine has a license to extract 4,200 m^3 of water daily from the river. However, during dry months (June to September), water supply from the Mara River can be limited as the river often dries up. Surplus inflows from rainfall and runoff normally occur in the wet season. Photograph 2 shows some key facilities situated at the Rama deposit area of NMM.

Photograph 2. Some key water management facilities at the Rama area of the North Mara Gold Mine

Management of the Evolving Water Management System

The original design of the water management system required the supply of fresh water from the Mara River to meet the process water demand. Numerous changes to mine site operational conditions have occurred since 2006 which have transformed the site water balance from deficiency to surplus. The most significant change has been new mining activity at the Gokona pit and the Gena pit, where pit inflows and waste dump/stockpile seepages were added to the water management system. These additional inflows were transferred to the existing Tailings Dam.

To cope with the new changes, NMM initiated the effort to develop a site wide water balance model to understand the dynamic flow sources. In the meantime, test work has been carried out to evaluate the suitability of replacing river water with site runoff as a source of makeup water to the process plant.

The water balance model for NMM has the same setup and capability as the one for BGM. The accuracy of the NMM water balance model is constantly checked against the monitoring data. Figure 3 shows the results of water balance analysis calibrated for the period between January 1, 2004 and June 7, 2009, and shows projected future volumes in the Tailings Dam. The increase in water inventory reflected in Figure 3 between June 2006 and July 2007 resulted from the inclusion of the new Gokona and Gena open pit operations in the site water management system. The simulation incorporated one of the possible management strategies to remove inflow from these open pits from the flow system. Results indicated that water levels may be stabilized, should the planned strategy be carried out. Several options are being evaluated at the time of preparation of this manuscript.

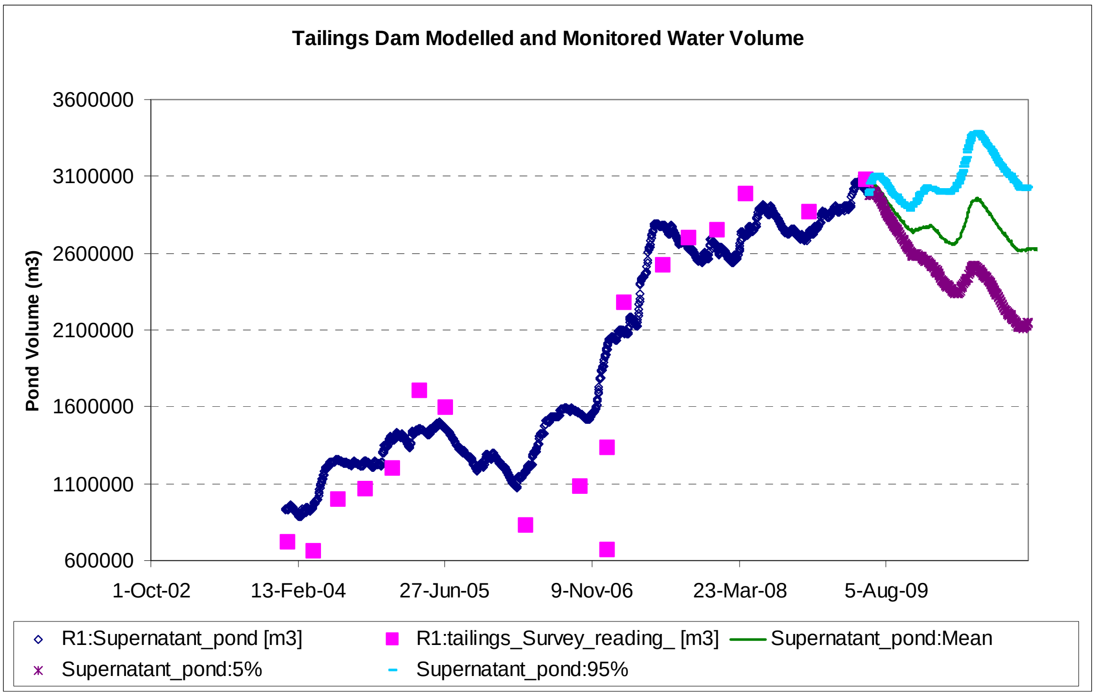


Figure 3. Results of water balance model analysis for the Tailings Dam at the North Mara Mine

Another major challenge for the mine operation is constant vandalism due to illegal local activities. For the water management system, water pipelines, flow meters, monitoring well equipment and pond liners are often targeted. This has greatly jeopardized the maintenance of normal operational conditions. For example, the liners of the contact water ponds have been repeatedly vandalised causing seepage releases. The liner pieces from the mine are used as building material in local villages (Photograph 3). These incidents have forced the mine to implement emergency measures that are sometimes undesirable to the overall water management strategy. The water balance model has been updated to allow simulation of various system disruptions and possible emergency measures.

Photograph 3. Vandalised contact water storage facility with liner stolen (A);
Liner pieces are used as local building material (B).

4. CONCLUSIONS

Real-life mine site water management systems often evolve with constant changes in day to day operation and/or mine planning. The ability to properly operate/modify the water management system is just as important as the design of the system. Early planning and quick adaptation to new operational conditions depend largely on the understanding of the site water balance. Successful site water management must be supported by adequate monitoring and close collaboration between processing, mining, environmental and other mine site functions.

5. ACKNOWLEDGEMENTS

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6. REFERENCE

Lin Shelp, M., Zhan, G. and Sibilski, U. (2009) “Real-time and stochastic estimation of mine site water balance.” Proceedings of the 8th ICARD, June 22-28, 2009, Skelleftea, Sweden.