Life-of-mine water management and treatment strategies

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Abstract

Water management, reuse and treatment are essential components of every mining operation. Integrated numerical models that represent the physical water balance and chemical mass balance of mine-water management systems can be used to predict water availability and chemical quality over the life of the mine.

Supernatant volume and water quality in a TSF during operation and closure was simulated using GoldSim and PHREEQC. Model results indicate that no treatment of TSF water during post-closure will be required, as long as ingress of seepage from the waste rock facility is effectively precluded after closure.

Keywords: Probabilistic models, predictive simulations, uncertainty, treatment costs, life of mine

Introduction

Water is vital for any mining operation. Water affects mineral extraction and processing, stability of pit slopes and mine workings, community relations and potential environmental impacts. Water management, reuse and treatment are essential components of every mining operation. The application of cost-intensive technologies such as reverse osmosis (RO) or nano-filtration is becoming increasingly common in mining operations—driven to a large extent by the requirement for low sulphate and total dissolved solids levels in both process waters and environmental discharges. As both capital expenditure (CAPEX) and operational expenditure (OPEX) of water treatment systems can be substantial (e.g. Dennis and Dennis 2017), adequate planning is essential to minimize costs. Moreover, ill-designed water treatment strategies may lead to compliance problems that are costly and can affect reputation, mine permits and social perception.

A thorough understanding of the site or process water balance and chemical composition at the different locations of the mine water management system (such as process ponds, tailings or waste rock storage facilities, discharge points etc.) is necessary to devise an efficient water reuse and treatment strategy. A major consideration that is frequently overlooked in the design of treatment systems is the long-term evolution of mine or process water quality, which can change dramatically due to either changing ore mineralogy or a progressive build-up of conservative solutes in process-reclaim circuits. Moreover, the volumes of water requiring treatment may also vary considerably with time. Retro-fitting treatment systems to resolve these problems can be more costly than designing for the long term from the outset.

Integrated numerical models to represent the physical water balance and chemical mass balance of mine-water management systems can constitute a powerful tool to avoid such issues and to proactively manage water on site and to design conveyance and treatment infrastructure. These models are used to predict water availability and chemical quality over the life of the mine. They can also be applied to simulate the performance of alternative treatment technologies or water management strategies, to size storage infrastructure and assess the benefits of blending or separating waters from multiple sources within an operation. This article outlines the methodology to construct these models and depicts applications in the mining sector.

Methods

Physical water balance model

The physical water balance model is constructed using the GoldSim software (GoldSim Technology Group, 2014). GoldSim is a flexible program which permits physical mass balance calculations to be performed at any specified point within a mine water conveyance system or a mineral processing circuit. For all such points, referred to as elements, graphic output can be generated with a high degree of self-documentation. Multiple elements performing different functions are also graphically represented and the inter-relationships between elements can be displayed such that it is generally easy to visualize the model structure.

The physical water balance model is focused on the volume of water moving through the system. The movement of chemical mass, associated with the movement of water, is addressed in the same model but as a parallel structure. With the exception of flow-dependent factors related to water quality (such as the calculation of dilution ratios), the physical water balance portion of the model is independent of the chemical mass balance. The chemical mass balance is described below.

Incorporation of uncertainty

A GoldSim model can be designed as a probabilistic, dynamic simulator, running continuously through the historical period and into future mine life in a sequence of time-steps with selected inputs permitted to vary within defined stochastic distributions. The model provides continuity in time through the use of stock elements that track the accumulation of water in the system and allow these to influence other components of the model. Additionally, the model can use a calendar to introduce or vary operational rules at specified points in time, or to simulate seasonal variation of inputs.

As a simulator of a complex system, the GoldSim incorporates uncertainty. Uncertain inputs can include for example future precipitation depths and operational factors such as pit dewatering flows. GoldSim addresses uncertainty by using Monte Carlo simulations to propagate uncertainty through the system. In a Monte Carlo simulation, each uncertain variable is input as a spectrum, based on a probability distribution. The Monte Carlo simulation repeatedly samples the value distribution and repeats the model evaluation with a different set of input parameters during multiple model reruns or 'realizations'. A Monte Carlo simulation will typically run up to 1000 realizations, resulting in a large number of independent results representing a probability distribution for the system.

An important fraction of the uncertainty within a mine site water balance model is often associated with the climatic inputs. Daily precipitation and pan evaporation can be stochastically sampled from probability distributions derived using historic climate data for the site. Other water balance components can also be modelled with stochastic elements, for example to represent the variable availability of pit sump pumps as a result of proximity to active mining areas.

Geochemical mass balance model

The geochemical mass balance model is constructed using the GoldSim Contaminant Transport Module (GCTM). The key inputs to the GCTM comprise concentration values for each parameter of concern or interest at each source-term, for example acid waters or process solutions, including pits, leach pads and waste rock facilities (WRF). The concentration inputs for each source-term are variably included as: (i) constants, (ii) flow-dependent variables, or (iii) partially flow-dependent variables.

Following the assignment of geochemical inputs to each source-term, the GCTM integrates the concentration values for each chemical parameter with flow volumes generated by the GoldSim water balance to yield a chemical mass load. During model execution, the movement of chemical load through the sequence of transport, storage and mixing stages of the model is simulated. At each point of mixing, the GCTM calculates an aggregate mass load for each chemical parameter. This is then divided by the gross water volume to produce an adjusted series of concentration values. Certain chemical reactions, for example precipitation of gypsum when saturation is reached, can also be integrated in the GCTM if these reactions are appropriately transcribed into the model by means of customised lookup tables.

The GCTM functions as an integral subcomponent of the GoldSim water balance model. Thus, the GCTM can perform water quality simulations for an infinite range of scenarios with respect to climatic inputs or facility discharge chemistry and flow permutations.

Presentation of model outputs

Following the execution of any model run, GoldSim can generate results for any model element within the water management system. Denominated 'reporting boxes' permit analysis of temporal trends with respect to virtually any variable within the model structure, for example the volume of seepage emanating from any individual WRF, pregnant solution volumes derived from heap leach pads, or projected variations of discharges from water treatment facilities. The chemical water quality results of the GCTM can also be visualized or exported at each of the 'reporting boxes'.

Typically, probabilistic time-series outputs are exported to Excel, formatted and graphed as flow rates, storage volumes or water chemistries through time. The median value (50% of all values calculated by the model), 5th and 95th percent values within the probabilistic range or even more detailed percentiles can then be easily plotted.

Case Study

The approach was applied at a mine in South America with a net-positive site water balance, where supernatant from the tailings storage facility (TSF) is fully re-used in the process plant during operation, but discharge of excess water to the environment will be necessary after closure (Figure 1). A physical water balance and chemical mass transport model was developed in GoldSim combined with PHREEQC (Parkhurst and Appelo 2013) to simulate and assess different strategies to ensure environmental compliance of any discharged water.

Results and Discussion

TSF Water Balance

Stochastic results for the TSF supernatant volume during operation and closure are shown in Figure 2. Water balance calculations indicate that during operation the supernatant volume fluctuates annually, responding to seasonal variations in rainfall and evaporation and reuse of water for mineral processing. During this period, the probability distribution displays a wide range of possible supernatant volumes, mainly due to the uncertainties associated with random climate input data. After closure, in absence of water abstraction for processing purposes, the stored volume rapidly increases to the maximum design value and any excess water is discharged towards the pit lake via the spillway. This is intended in the closure strategy to form a permanent water cover over the tailings which inhibits long-term sulphide oxidation. There is very little spread in the probability distribution during closure, because rainfall largely exceeds evaporation during most of the year and no other major sinks are affecting supernatant volume.

Water quality predictions

TSF supernatant water quality (pH and sulphate as examples) based on the 50th percentile flows from the TSF water balance is shown in Figure 3. During mine operation until 2022, supernatant pH fluctuates around values of pH 8-9, due to lime introduced with the tailings slurry. After closure in 2023, pH rapidly

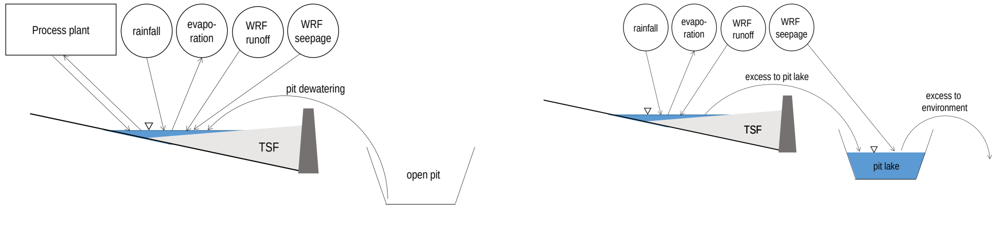

Figure 1 *Schematic case study TSF water balance during operation (left) and after mine closure (right).*

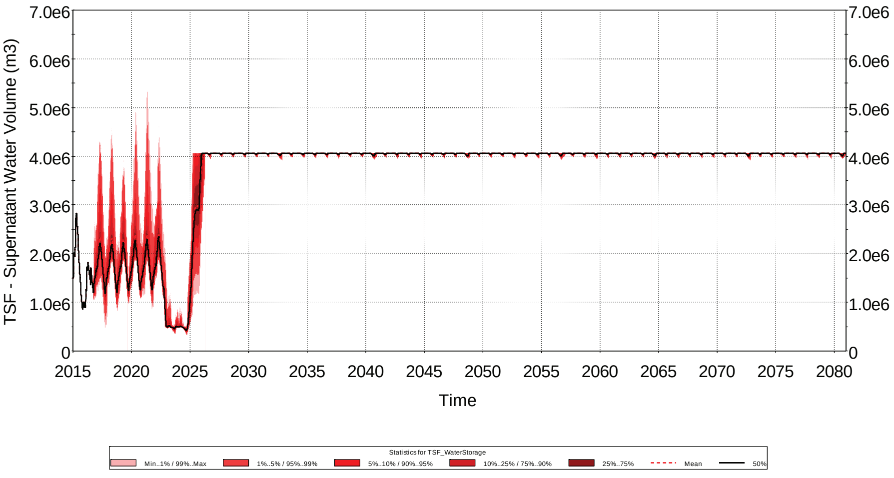

Figure 2 *Stochastic results for the TSF supernatant volume during operation and closure.*

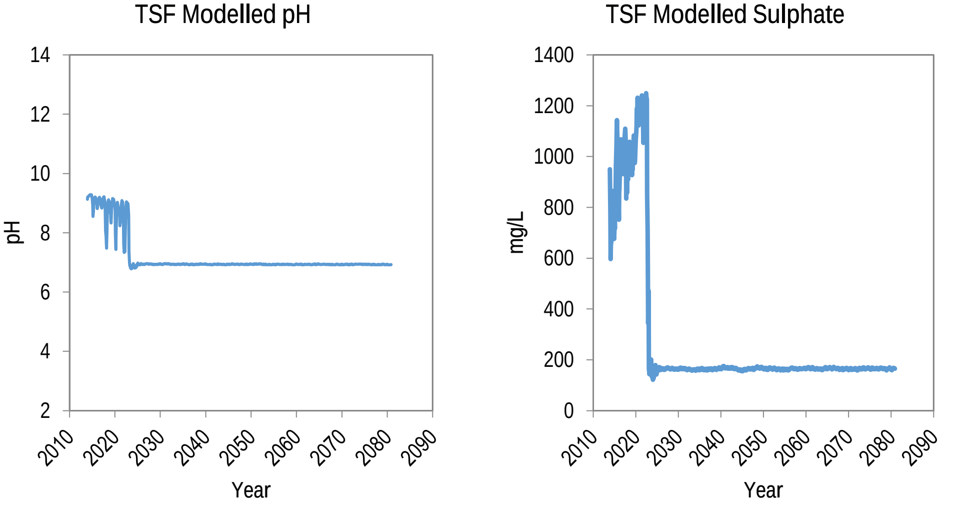

Figure 3 *TSF supernatant water quality predictions.*

stabilises near pH 7. Sulphate concentration increases continually during operation, mainly due to the loading from WRF seepage which grows proportionally to the deposited waste rock mass, plus inputs from the process plant. After closure, as WRF seepage and process waters are no longer routed to the TSF pond, sulphate concentration in the supernatant rapidly falls to less than 200 mg/L. Concentrations of dissolved metals (not shown) are also compliant with regulations after closure, and TSF supernatant is therefore apt for discharge to the pit lake or directly to the environment without treatment.

Conclusions

Water quantities and qualities within a mine water management system can change substantially during mine life as the mine configuration and ore mineralogy evolve. Mine water management, reuse, and treatment strategies that consider these changes result in a solution fit for purpose in the long term. More importantly, a strategic long-term solution avoids the consequences of inadequate planning, which include detrimental or even catastrophic water excess or shortage and costly retro-fitted solutions.

In our case study, results indicate that no treatment of TSF water during post-closure will be required, as long as ingress of seepage from the waste rock facility is effectively precluded after closure. The numerical model helps to define an optimized post-closure water management strategy, to reduce operational and closure risks, and in this case to avoid unnecessary investments (e.g. post-closure TSF water treatment infrastructure).

Integrated physical and chemical water balance models of a mine water management system assist the mining operation in day-to-day operation and strategic mine planning in the long term. Integrating technology and expertise early in the planning cycle can substantially reduce long-term cost.

References

Dennis I, Dennis R (2017) Financial Modelling for Mine Discharge Treatment Options, In: Wolkersdorfer C, Sartz L, Sillanpää M, Häkkinen A (eds.), Mine Water and Circular Economy, Lappeenranta University of Technology, p 649 – 655

GoldSim Technology Group (2014) GoldSim User Guide, GoldSim Technology Group LLC, Vol. 1+2.

Parkhurst DL and Appelo CAJ (2013) Description of input and examples for PHREEQC version 3—A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Techniques and Methods, book 6, chap. A43, 497 p, available only at https://pubs.usgs.gov/tm/06/a43/