Mine Water Management – Dynamic, Probabilistic Modelling Approach

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Abstract

This paper presents a holistic approach to mine water management. The proposed approach provides a framework and methodology for integrating different components of mine water infrastructure by explicitly representing the relationships, feedback mechanisms and uncertainties about the conditions and processes involved, using a dynamic, probabilistic simulation method.

Key words: water balance, water management, modelling

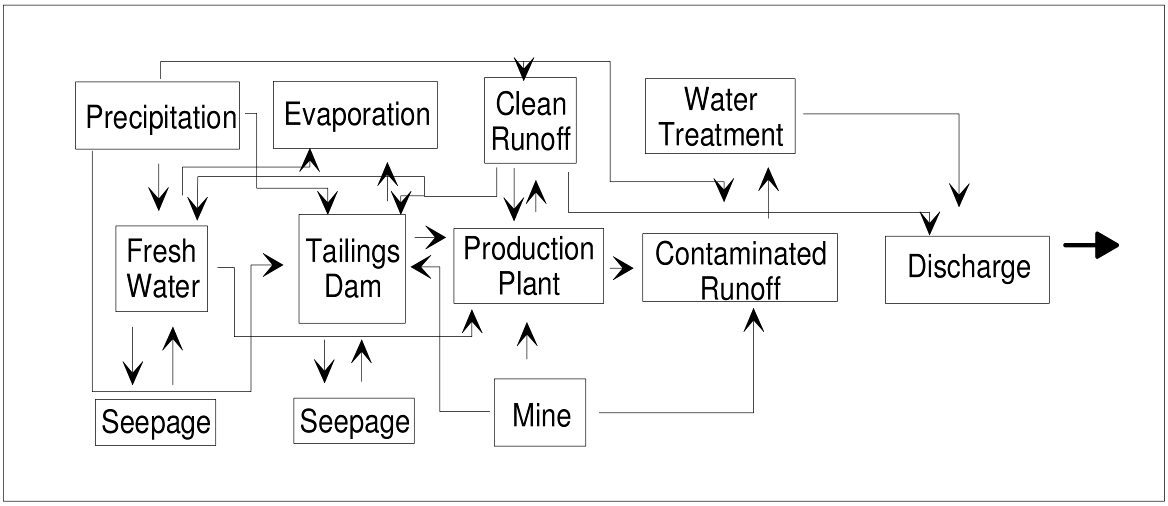
Introduction

Mine water management is a fundamental issue that affects most mines world wide. The risk of surface water and groundwater contamination caused by mining activities and any following potential environmental consequences call for careful planning and operation of mine water infrastructure.
The need to provide an adequate reliability of process water supply and assurance of the compliance of discharge water quality and quantity with local environmental legislation and with best practises is becoming equally important. The level of exposure of mining companies to issues relating to effective water management practises and methods is however, one of the main concerns facing the industry, especially in the developing parts of the world.

Typical approach to mine water balance

Although every mine is different, in general the water balance components can be typically identified as shown in Figure 1.

***Figure 1** Simplified schematic of typical mine water balance components*



Typically, mine water balances are focused around the tailings area. The classic water balance approach usually involves building a deterministic model in which respective elements of the water cycle are usually represented by using averaged values of system variables over modelled time steps (usually months or years). Many of these variables are well known in advance and can be fairly precisely defined. However, there is an extensive group of variables which are probabilistic by nature and using their average values limits the accuracy and usefulness of the water balance model outputs.

A deterministic model usually does not account for extreme meteorological events, which may have direct implications for water supply and disposal and quite often determine important design criteria and constraints that have to be met during the design and approval processes.

The classic approach of estimating the water balance of a mining system by using a deterministic model with simplifying assumptions, while still valid in many cases, is found to be lacking the necessary subtleties to address complex systems such as current large mining operations (Julien et al. 2005).

Proposed alternative approach

An alternative approach which is presented in this paper involves development of an integrated water balance model in which all water balance elements are connected into logical and hierarchical network and influence other elements in the network instantly. Model time steps can be automatically shorten as necessarily to accommodate greater variability of certain water balance components (rainfall or emergency pumping for example) as necessarily. The model variables can be expressed as stochastic parameters which, rather than having an average or "most likely" value, represent statistical distribution of possible values.

This kind of approach makes it easy to investigate the impact of respective elements on other parts of the system and also allows for efficient probabilistic approach to uncertain parameters using Monte Carlo technique.

Modelling Tools

The water balance model described in this paper was built using GoldSim, a dynamic system modelling package, which is a graphical object-oriented modelling environment with an in-built capacity to carry out dynamic probabilistic simulations. It has been used extensively in mine water balance studies in North and South America, Europe, Africa and Australia.

GoldSim has many different types of objects, which can be coded depending on user requirements, as well as a set of pre-coded elements which can be used directly in water balance applications.

Example of Application

A fictitious example based on real-life problem has been created to show the advantages of the described method. The example represents an open cut mine located in a monsoonal climatic zone with highly variable rainfall. The mining process generates a stream of potentially acid generating (PAG) tailings which have to be stored submerged under water to prevent oxidation. The mine plant production circuit resulting in production of PAG tailings requires high quality water which can be sourced from few available but limited and time dependent sources.

The problem was divided into two components – flow and mass transport, defined separately but linked together to deliver comprehensive output. The flow component represents the logic of water flow (natural and mining related cycles) in the mine water infrastructure, explicitly representing elements of the infrastructure and relations between them. The model also represents processes occurring during the mine life and feedback mechanisms between them, like production rate changes resulting in various rates of tailings dam filling up over time, which in turn controls the staging and speed of progression of the tailings dam embankment.

The water quality component of the model mirros the structure of the flow system. By applying model-calculated flow rates to both water and solids, a chemical composition database with a provision for diffusive fluxes is generated and allows for inspection of the simulated mine water quality in each of the mine water infrastructure components at any point in time.

The main driver for the model is a climatic component, which generates rainfall and seasonal evaporation as well as using an embedded AWBM model (Australian Water Balance Model-Boughton 1996) generates runoff from various types of surfaces which are variable in time during mining operations.

Example Solutions

Presented below are a few examples of many potential applications of the dynamic, probabilistic modelling to the complicated scenario that is described above. These examples will show the flexibility and usability of the approach, and how it efficiently copes with real world problem.

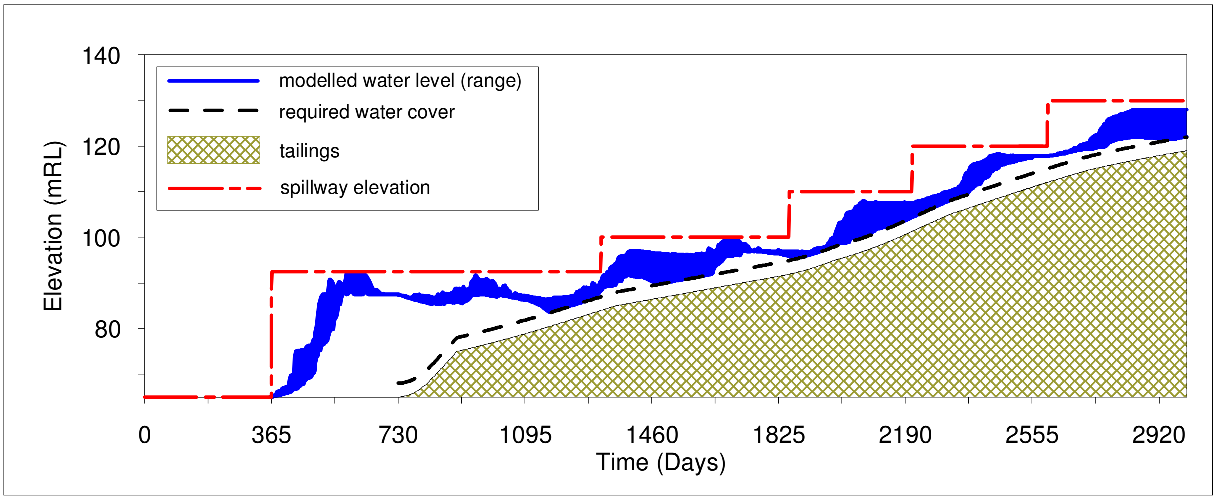
Rainfall

Using average rainfall does not necessarily work in models representing highly variable, tropical or monsoonal climates, especially when addressing extreme conditions that impact on safety and critical design requirements for mine infrastructure components like tailings dam capacity to store contaminated water even underconditions of intense but occasional rainfall. This problem was addressed by coding a stochastic rainfall generator within the water balance model allowing, , based on historical set of data, the generation of random strings of rainfall of similar statistical characteristic to the original data. There is a number of such generators described in hydrological literature which can be easily applied (Boughton 1999). Using a Monte Carlo approach, it is possible to generate thousands of years of synthetic data and to analyse the performance of the mine water supply components (including water quality) under each of those variable sets of conditions. Results can be easily summarised and analysed, inspecting for example, maximum concentrations and frequency of their occurrence for statistical purposes. As a result the reliability of the model generated climatic conditions increases substantially over the "classic" approach.

Tailings storage design

The dynamic approach can also assist with designing the required dam embankment height and its progression over time. The assistance with planning of the construction schedule helps with expenditure planning and efficient allocation of the capital during, most often critical, early months and years of operation. Figure 2 shows the analysis of the required tailings dam embankment height defined by the elevation of the spillway. This elevation would provide enough storage for supernatant water released from tailings during the deposition process and runoff collected over the wet season to supply mine plant operations during the dry season, maintaining in the same time the required PAG tailings water cover and minimising spills from the dam. The challenge was to define minimum volumes of water to store which would provide continuous water supply during the mine operation under various foreseeable climatic and operational conditions. Variable, dynamic time step length in this case helped with estimating the optimal pump capacity required to maintain the water within desirable levels. The analysis helped also with identifying critical periods of time when water shortfalls are likely to occur.

Figure 2 *Model simulated water level changes in the tailings dam with model-generated progression of tailings deposition and resulting, proposed spillway elevation changes over time*



Production water shortfall forecast

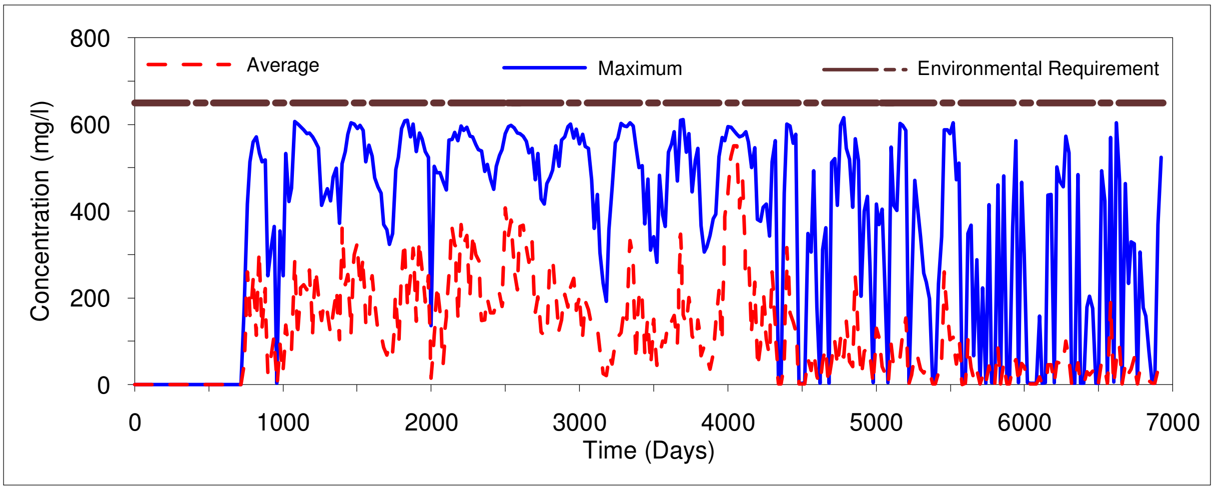
The model can easily identify potential water shortfalls which can occur during the life of the mine, as well as allowing an examination of the sensitivity of respective model elements to the specified output criterion (reliability of water supply in this case). That possibility, in turn, assists greatly with identification of favourable areas of improvement in the overall water infrastructure prior to its implementation in real life.

In this example, the model assisted with identification of fresh water deficit in the production circuit and helped with identifying additional required volumes of water and their temporal distribution.

Meeting environmental discharge criteria

The model proved to be very efficient with analysing discharge water quality and perfecting the discharge mechanisms which would guarantee that environmental discharge criteria are met. Applying Monte Carlo approach to this very sensitive aspect of the mine operation increased the reliability of the model generated outputs and increased the confidence that the target criteria will be met under varying climatic conditions. Figure 3 shows the model generated range of chloride concentrations in the mine discharge water compared to the environmental discharge criterion for chloride.

Figure 3 *Model-generated concentrations of chloride in the mine discharge water*



Cost Tracking

Another very important aspect of the flexibility of the model is that it can easily accommodate a cost tracking routine, which can allow for quick comparisons of mine operation costs for different mine operating scenarios. Having an "all-in-one" structure requires minimal effort to update various components of the model and in the same time guarantees availability of instant answers to questions that inevitably emerge regarding the costs of various aspects of mine operations.

Conclusions

The above example shows a very practical use of the proposed probabilistic approach which, due to its flexibility, can be easily implemented to address fairly complex real-life problems. Using a dynamic, probabilistic model with Monte Carlo simulations allowed for a flexible approach which helped with addressing a number of potentially critical issues with the design and operation of water management on site. It also aided with permitting processes forming a strong base to support the submitted applications. This approach to mine water balance modelling has been successfully applied in a number of projects around the world, including Australia, Oceania and South-East Asia.

References

Boughton W. (1996) AWBM Catchment Water Balance Model. CRC for Catchment Hydrology, Monash University.

Boughton W. (1999) A daily rainfall generating model for water yield and flood studies. CRC for Catchment Hydrology, Report 99/9

Michael R. Julien MR, Mike Gowan, Przemek Nalecki, Mayana Kissiova (2005) Water balance and its integration in mine operation through the use of real-world systems modelling tools. 2005 Symposium Mines and the Environment, Rouyn-Noranda, Quebec, Canada.