Life-Cycle Water Balance Modelling as a Tool for Water Management Risk Assessment to Minimise Legacy Effects

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Abstract

This paper presents a cyclic methodology for non-operational water management risk assessment to help minimise legacy effects by using an integrated mine water balance as a characterisation tool. The methodology aims to identify possible legacy effects that a current mining operation might pose; and assess the effect that recommended mitigation measures might have to reduce the identified effects. An example case study is presented using the proposed methodology for a platinum mine in South Africa.

Keywords: Integrated water balance model, water management risk assessment, GoldSim

Introduction

Operational mines have multiple entities that require comprehensive water management to ensure minimal risk of contamination to the environment and continual production capacity throughout the life of the mine. The day-to-day operations do not necessarily consider the closure status of the mine and the subsequent legacy effects those entities might have, if left unrehabilitated during operation, when these entities cease operation, temporarily or permanently. Typically, in water balance modelling a key assumption is that all entities are managed according to the design criteria and for the entity's designed lifespan or the expected Life-of-Mine (LOM). Therefore, the effect of an entity being non-operational at any instance in its lifespan, in relation to the entire mining operation, is typically not considered. An abrupt change in the lifespan and operational scheduling of an entity could potentially have a larger legacy effect than the original lifespan of that entity considering its planned closure date. This paper presents a non operational water management risk assessment methodology to identify and minimise legacy effects. It also presents how an integrated mine water balance can be used as a tool to undertake the assessment.

Water Management Risk Assessment

Water management is a structured approach to managing water across a site that is usually driven by a preferred environmental outcome and a water balance model is a tool developed to assist in achieving this outcome (Punkkinen *et al*., 2016). The principle of mass conservation is critical when constructing a water balance model and should be followed throughout (Department of Water Affairs and Forestry, 2006). A water balance model replicates the flow network across a site and simulates where water is stored and how water is moved. Incorporated into a water balance model is the environmental flow generated by the site in the form of rainfall, runoff, evaporation and infiltration, site-related flows as well as any site-related configurations/assumptions (Julien *et al*., 2005).

In this study, GoldSim was used as a modelling software to dynamically model an integrated mine water balance and can be used as a tool in water management assessments. As mining conventions and management over the life of a mine continuously change an additional level of complexity in the water balance model is required to account for the operational changes. GoldSim has the capability to model complex site-specific systems that can be continuously updated/

modified. This modelling software uses Monte Carlo simulations to generate a probabilistic set of outcomes (Krogerusk & Pasanen, 2016). This provides a flexible approach to water management of a site (Nalecki & Gowan, 2008).

Quantifying the environmental risk of an entity with regards to its potential legacy effect at any point in its lifespan is an important consideration when modelling the status of the mining operation. Current and potential legacy environmental effect quantification provides the opportunity to identify possible interventions or new technologies to minimise the legacy effect an entity might have on the environment. Financial implications should be considered together with the environmental effects and risks when assessing the possible interventions or new technologies as this could require larger financial investment or risk, making the possible intervention undesirable.

The cyclic methodology for the non-operational water management risk assessment (Figure. 1) uses a multi-criteria approach to assess and rank the potential legacy effects of each entity, in an integrated mine water balance, being non-operational at any instance in its lifespan.

As part of the methodology an integrated mine water balance model is developed. A mine specific list of potential legacy effects is then complied. This list is then used in determining the environmental and financial evaluation criteria of the risk assessment. Each entity in the integrated water balance model is assumed then to be non-operational, e.g., a prolonged halt in production, and evaluated on its potential environmental effects, as well as the probability of occurrence of these

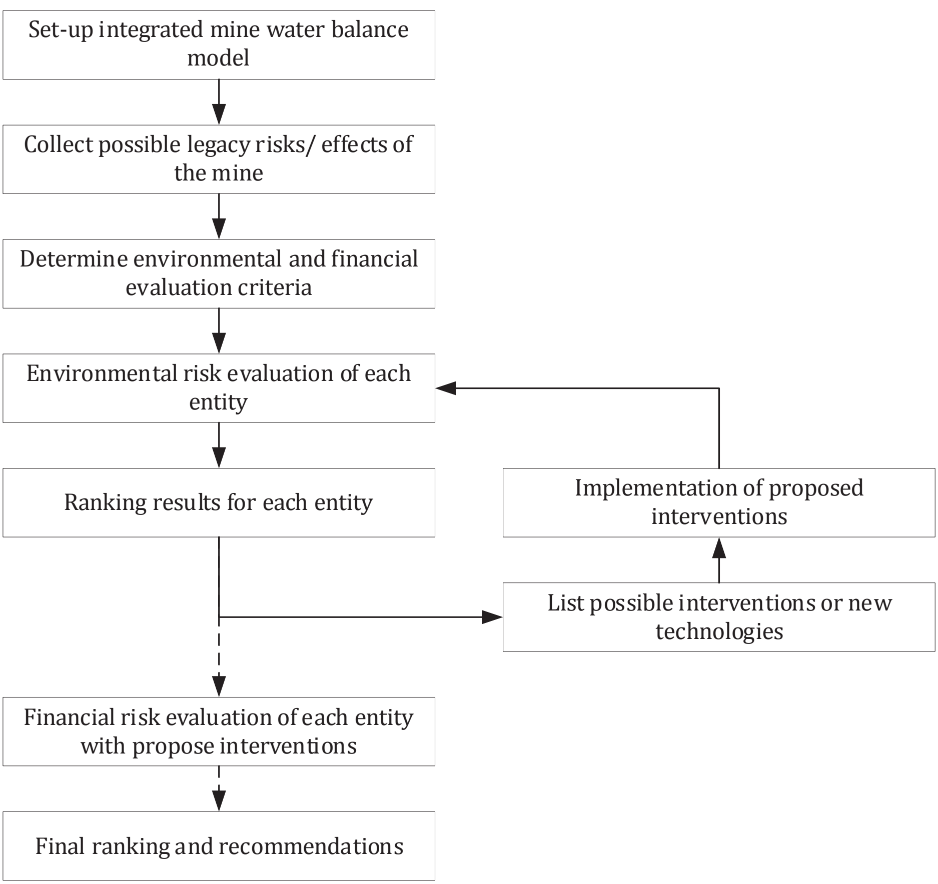

Figure 1 *Schematic of the proposed cyclical methodology for the non-operational water management risk assessment.*

effects. The entities are then ranked according to the evaluation results. A recommended list of proposed interventions is then compiled for each entity. Ranking of temporal urgency for intervention and/or mitigation provides guidance regarding entity prioritisation and potential for implementation of new technologies. The proposed interventions can then be applied in the integrated water balance model and non-operational water management risk assessment. Evaluation can then be repeated assuming the proposed interventions are implemented. The evaluation will indicate if the proposed interventions are expected to decrease the likelihood of legacy effects by comparing the re-evaluated environmental and financial ranking of the proposed interventions to the results of preceding evaluation iterations. This provides a final risk ranking when further iterations show no notable variance. Using the final ranking the most effective proposed interventions can then be recommended with the ranking indicating the recommended temporal priority.

Example Case Study

An integrated mine water balance model in GoldSim for an open cast platinum mine in South Africa is used to demonstrate the proposed cyclic methodology for a non-operational water management risk assessment. This example simplifies the list of mine entities in the assessment to avoid repetition of entities within the integrated mine water balance. The simplified list of entities includes an open pit, pollution control dam (PCD) containing stormwater runoff from a waste rock dump (WRD), PCD containing stormwater runoff from the concentrator plant area, tailings storage facility (TSF) and the TSF return water dam (RWD).

The legacy effects that the mine poses are the contamination of mine affected and surrounding areas; as well as contamination of water resources (surface and groundwater) in the area. In addition, the mine has altered the natural landform of the mining area which has resulted in land disturbances. These legacy effects were considered when compiling the evaluation criteria for the mine. A list of environmental aspects considered at each entity together with the financial aspects of the proposed interventions, with weighted percentages, were compiled (Table. 1). The evaluation criteria for the environmental and financial aspects were then determined (Table. 2).

The integrated mine water balance assumes that production was suspended, and all major operations ceased. It was assumed that the open pit did not pump any water and a pit lake formed. No ore was processed at the concentrator and thus no slurry was deposited on the TSF. The water balance also assumed that the water storage facilities were required to contain all stormwater generated from associated catchments and no additional water was imported to the mine. Using these assumptions, the initial environmental risk evaluation was undertaken, and each entity was ranked according to the lowest environmental score (Table. 3).

Table 1 *Environmental and financial aspects with associated weight percentage.*

Environmental			Financial		
Aspect	Description	Weight (%)	Aspect	Description	Weight (%)
Discharge Risk	Discharge risk to the environment from water storage facilities	30	Capital cost	New required infrastructure and/or upgrades/changes to the current system.	40
Land disturbance	Footprint of dirty catchment areas	10	Operational Cost	Pumping costs and ongoing maintenance	30
Open Pit System	Water quality and quantity in the unused pit/s	20	Permitting	Timing, specialist studies, approval viability	30
Contamination	From water storage facilities through discharge or seepage	40			
Sub-total		100	Sub-total		100

Table 2 Environmental and financial evaluation criteria.

Aspect	Rating			
	1	2	3	4
Environmental				
Discharge Risk	<1:1 year discharge risk	<1:10 year discharge risk	<1:50 year discharge risk	No change to discharge risk
Land disturbance	Major effect to environment	Minimum effect to environment	Effect limited to already affected areas	Reduction in already affected areas
Open Pit System	Seepage from pit to environment and effect to pit water quality	Major effect to pit water quality	Moderate effect to pit water quality	No charge
Contamination	Serious effect & impairment of ecosystem	Moderate effect to environment	Minimum effect to environment	No lasting effects
Financial				
Capital cost	Major upgrades / changes	Moderate upgrades / changes	Minor upgrades / changes	No upgrades/changes
Operational Cost - Pumping distance	>10km	<10km	<5km	<2km
Operational Cost - Maintenance	Major pumping required	Moderate pumping required	Minor pumping required	No additional pumping required
Permitting	Potentially nonviable	Viable, 3–5 years reg. process	Viable, 1–2 years reg. process	Within current Water Use Licence / Environmental Impact Assessment

Table 3 Environmental evaluation and ranking.

Aspect	Entity Rating				
	Open pit	PCD - WRD	PCD - Concentrator Plant	TSF	RWD-TSF
Environmental Score (%)	68	78	53	78	45
Environmental ranking	3	4	2	4	1

The ranking (Table. 3) indicated that the TSF RWD and concentrator PCD should be prioritised as these entities had the highest risk ranking, followed by the TSF, and then lastly the open pit and PCD containing stormwater runoff from a WRD. An intervention for each entity was identified and applied in the water balance. The proposed interventions for the TSF RWD included pumping excess stormwater from the RWD to the open pit, commencing with rehabilitation of the TSF side-slopes and reducing external clean water catchments. For the concentrator PCD proposed interventions included commencing with rehabilitation of the concentrator area to reduce dirty catchments and pumping excess stormwater to the open pit. The care and maintenance and rehabilitation plan for the TSF should commence and concurrent rehabilitation of WRDs should be considered. At the open pit, a pit lake study should be undertaken.

The evaluation for each entity was reiterated with these interventions and an updated risk ranking complied. A final risk ranking was then determined by combining the environmental and financial results (Table. 4). From the final risk ranking it can be inferred that the future mine planning should investigate the implementation of an integrated pumping system to allow all stormwater dams to pump to a central facility or pit where water can be contained and managed. The TSF care and maintenance and rehabilitation plan should continuously be updated throughout the life of the facility when major operational changes occur to ensure its continued validity. A closure

Table 4 Final environmental and financial evaluation and ranking.

Aspect	Entity Rating				
	Open pit	PCD - WRD	PCD - Concentrator Plant	TSF	RWD-TSF
Environmental Score (%)	68	80	70	78	55
Environmental ranking	2	5	3	4	1
Financial Score (%)	75	65	50	58	50
Financial ranking	4	3	1	2	1
Final ranking	4	5	2	3	1

pit lake assessment should be undertaken and anticipated effects on the groundwater sources in the area quantified. Lastly concurrent rehabilitation of WRDs should be considered in the current water management plan of the mine.

This case study demonstrates that the quantified ranking of the rehabilitation schedule could decrease legacy effects in future as proven by the increasing environmental scores of the reiterated assessment when compared to the environmental scores in the initial assessment. This methodology can thus be applied cyclically to assist in the identification of possible interventions or new technologies to minimise legacy effects throughout the life cycle of the mine.

Conclusions

The example case study illustrates how the proposed methodology can be used in practice. Applying this methodology cyclically has been quantifiably proven by this study to assist in the identification and sequential implementation of mitigation measures relating to potential legacy effects from the evaluated entities of the mining operation. This allows for a pro-active approach in identifying possible interventions while compiling the water balance for prevailing site conditions. Documenting these recommendations as part of a water balance project can be used in future mine planning to aid in reducing legacy effects.

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References

Department of Water Affairs and Forestry, 2006. Best Practice Guideline G2: Water and Salt Balances. South Africa.

Julien, M.R., Gowan, M., Nalecki, P. and Kissiova, M., 2005. Water balance and its integration in mine operation through the use of real-world systems modelling tools. In 2005 Symposium Mines and the Environment, Rouyn-Noranda, Quebec, Canada.

Krogerus, K. and Pasanen, A., 2016. Management of water balance in mining areas–WaterSmart.

Nalecki, P. and Gowan, M., 2008. Mine water management–Dynamic, probabilistic modelling approach. Rapantova, N. & Hrkal, Z, pp.533-536.

Punkkinen, H., Räsänen, L., Mroueh, U.M., Korkealaakso, J., Luoma, S., Kaipainen, T., Backnäs, S., Turunen, K., Hentinen, K., Pasanen, A. and Kauppi, S., 2016. Guidelines for mine water management. VTT Technology, 266, pp.1-157.