Developing Integrated Water Management Models to Address Water Related Risks and Provide Resilience in the Mining Industry

Scott Anderson[1], Tyler Tinkler[2]

[1]*GHD, 999 Hay Street Perth WA 6000, Australia, scott.anderson@ghd.com*

[2]*GHD, 23 Honeysuckle Drive Newcastle NSW 2300,*
Australia, tyler.tinkler@ghd.com

Abstract

Integrated Water Management models comprises a spatially lumped representation of the components of a mine water management system and their interactivity including water supply and conveyance infrastructure, hydrological and hydrogeological processes, ore processing, water treatment and waste disposal. The model can be used to assess different operational and/or expansion scenarios and their evolution over a mine's life to provide probabilistic outputs of impacts to the water system and identify areas where capacity is constrained and optimisation opportunities exist. We examine the potential benefits and limitations through case studies in both underground and open cut operations, throughout the mine life cycle.

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Introduction

An Integrated Water Management model comprises a spatially lumped representation of the components of a mine water management system (MWMS) and their interactivity including water supply and conveyance infrastructure, hydrological and hydrogeological processes, ore processing, water treatment, waste disposal and tailings storage facilities. The model can be used to assess different operational and/or expansion scenarios and their evolution over a mine's life to determine the impacts to the water system and identify areas where capacity is constrained and optimisation opportunities exist. The model can provide answers to the following water related issues:

- **What** – what type of capacity constraint exists (water surplus/deficit or inadequate quality)?
- **Where** – where does the capacity constraint exist (tanks/dams/pumps/pipelines)?
- **When** – when does the issue manifest (immediately or in several years)?
- **Likelihood** – what is the likelihood that the issue will manifest (under climate change)?
- **Impact** – which mine performance measures are impacted (ore production, safety or environment)?
- **Magnitude** – how big is the impact and what will the cost be (financial/environmental/social)?

Methods

Our approach to water and contaminant balance models incorporates all components of a MWMS, as well as the interdependencies between them to provide probabilistic outputs of the magnitude of impacts. We employ a multidisciplinary approach that includes inputs from hydrological, hydraulic, hydrogeological, chemical and tailings practitioners. The modelling incorporates these inputs and the probabilities surrounding them to provide improved predictions of a MWMS behaviour and then assigns a likelihood to a certain impact occurring. The most basic form is a semi-distributed spatially lumped catchment mass balance approach (Ladson 2004), expressed as ordinary differential equation that is typically solved in minutes or hours with an explicit numerical scheme. Catchment runoff is often an important component, typically estimated using the Australian Water Balance Model (Boughton 2003) for which regional parameters are available (Boughton and Chiew 2003), but site specific calibration is preferred, especially for land uses unique to mine sites (Kunz *et al* 2013).

Rainfall inputs are typically sourced from a synthetic historical record (DSITI 2019). These records are limited to the availability of nearby rain gauges, orographic effects and the daily time scale limits the temporal resolution of the models.

Groundwater inputs are typically estimate separately, with varying degrees of coupling employed depending on the complexity of the interaction (Rassam and Werner 2008). Tailings storage facilities are commonly present and often represent the single largest water flux within the system (Watson 2000).

Traditional water and contaminant balance models may consider each component in isolation (e.g. tailings storage facility) and only assess a static design scenario rather than changes over the mine life. Impacts on other components of the system are often ignored or based on simplistic assumptions that may not adequately reflect the system complexity. This is especially true under rare combinations of events where MWMS are pushed to their limits and can behave in unexpected ways that are not anticipated from a traditional deterministic design approach.

The concept and advantages of integrated MWMS models is widely documented (Gosling 2010, Younger 2006), and such models are successfully implemented across most mine operations in Australia for regulatory and operational reasons. This paper focuses on contrasting estimates from "simpler" design methods and MWMS models. Through two case studies successfully implemented in lithium and gold mines, we demonstrate situations where simplistic "worst case" design assumptions may lead to under or over design.

Case study 1: Environmental containment design for small underground gold mine

Underground mines are not afforded the luxury possessed by established open cut operations of large mining voids for water storage. Many operations are expected by decision makers and regulators to be 'zero discharge' which is often poorly defined and understood. Simplistic design approaches may be adopted to demonstrate compliance with this expectation that underestimates the actual likelihood and leads to unexpected outcomes during the operation of the mine. A simplified schematic of a proposed new underground mine in Central West NSW is

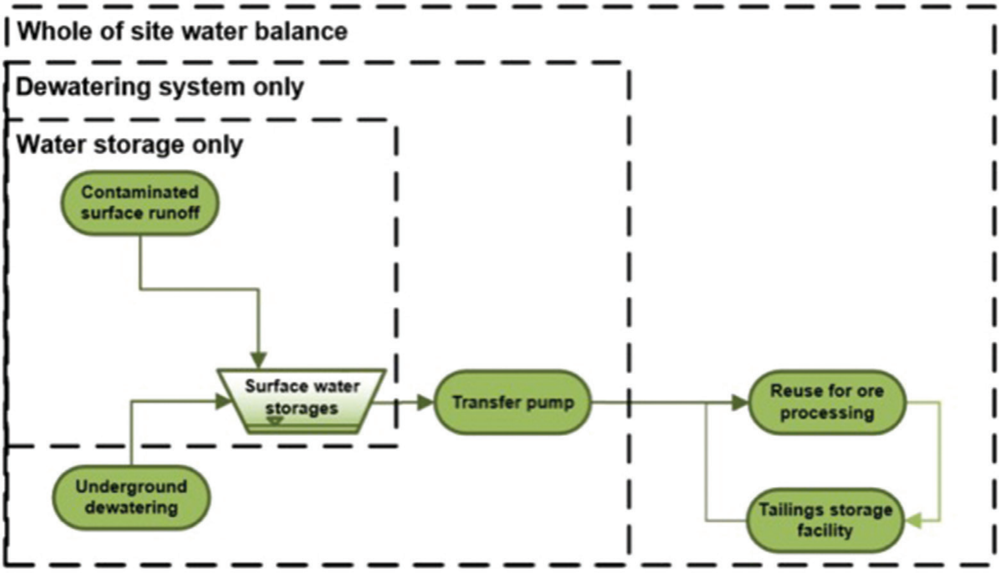

Figure 1 *Conceptual MWMS schematic.*

shown in Figure 1. The project proposed to transfer ore and water to another existing mine for processing.

Figure 1 shows the varying levels of scope of the assessment of the performance of the environmental containment of the MWMS. Throughout the design of the project, as more information was available, the scope of the assessment was expanded and the performance reassessed, as shown in Table 1.

Table 1 shows that considering the surface water storage only for containing runoff from the catchment (a traditional hydrologic design) does not represent the actual performance of the system because the initial water volume of the storage depends on the operation of the remainder of the system. Considering only the dewatering system captures the limitations of the transfer pump and variability with predicted groundwater inflows over time. During the peak of groundwater inflows, that typically occurs as the decline reaches final depth in the first half of the mine life, the dewatering capacity of contaminated runoff is reduced by the need to continually dewater the underground mine for its safe operation.

However, Table 1 shows that ultimately, the performance of the system was limited by the net losses from the processing and tailings emplacement operations. Improving the performance would require additional contaminated water storage, however the integrated modelling can demonstrate that this can be located at either the new or existing mine site, potentially reducing costs.

Consideration of cumulative risks of the of the full mine life (with varying groundwater inflows and ore processing rates) which is relatively short compared to traditional public infrastructure, can also better inform decision makers.

In summary Case Study 1 has demonstrated how an Integrated Water Management model coupled with probabilistic inputs delivers can be used to answer the following:

- **What** – potential downstream surface water impacts
- **Where** – at either the main or satellite site
- **When** – the early part of mine life as the decline reaches full depth
- **Likelihood** – 86% chance of exceedance during life of mine of requirement for off-site discharge
- **Impact** – actual and perceived downstream water quality impacts

Through the understanding of all these issues, a solution that was optimised for both cost and risk to the miner was able to be achieved. This would not have been the case if simpler modelling techniques were used. This limitation of this approach is the availability of information to inform design and feasibility budgets, which is not also possible in the permitting and design schedule.

Case study 2: Operational water surplus and deficits for an open cut lithium mine

Preconceived ideas about specific issues within a MWMS can often limit the scope of water balance assessments leading to a form of confirmation bias in the outcomes. In this situation, a mine operator may only want to examine a few narrow scenarios such as wettest or driest year in recent history and only for the ensuing year or two. This can have the impact of over or under design and also misses the opportunity to identify potential other MWMS constraints or opportunities with reasonable planning and implementation timeframes to affect outcomes.

Table 1 *Environmental containment system performance.*

Design basis	Environmental containment performance - initial	Environmental containment performance – under peak groundwater inflows	Environmental containment performance – life of mine
Water storage	1% AEP 72 hour duration	1% AEP 72 hour duration	1% AEP 72 hour duration
Water storage capacity and dewatering system	1% AEP	4% AEP	16% chance of exceedance during life of mine
Whole of site water balance	7% AEP	14% AEP	86% chance of exceedance during life of mine

Case Study 2 examines an open cut lithium mine in Western Australia to demonstrate the advantages of Integrated Water Management models coupled with probabilistic climate inputs. The mine is located in one of the wettest parts of the state and therefore the conventional wisdom had been that surplus contaminated water leading to offsite discharge was the primary concern of the MWMS. This was not unfounded as it had been the major MWMS issue observed by the mine operator over the preceding decade. A comprehensive water balance model was developed for the MWMS that utilised the previous 50 years of observed climate data applied sequentially in a "semi-Monte Carlo" approach over the ensuing 15 years of the mine's life. The model accounted for changes to the MWMS over that timeframe including dewatering rates, ore processing volumes and development of additional tailings storage facilities. The advantage of this method is that it subjects the MWMS to a large range of the historically observed climate patterns over the remaining mine life and therefore provides results that are probabilistic instead of deterministic.

Figure 2 shows the outcomes of water surplus or deficit risks as determined by the water balance model of the mine. From Figure 2, it can be observed (as the mine operator suspected) that surplus water leading to offsite discharge was indeed a significant risk over the remaining mine life. However, what was not expected was the significant risks of processing water shortages. The risk of process water shortages was not expected to manifest until 2024 but grows significantly to approximately 50% by 2027 before falling away for the remainder of the mine life. Had a model been developed that just examined a wet climate scenario and only for the ensuing 1 to 3 years (as was initially proposed) then the water deficit risk would not have been identified as early as it had. This has provided the miner with sufficient time to examine and implement mitigation measures which significantly reduces the risk of processing water shortages and the impacts to mine revenue and profitability associated with it.

Following identification of the water deficit risks from the initial water balance modelling work, the operator wished to explore strategies to mitigate these risks. The only feasible options identified included a combination of both additional storage volume and additional water sources. This could be in the form of increasing the storage capacity of existing onsite storages coupled with a new locally acquired offsite water

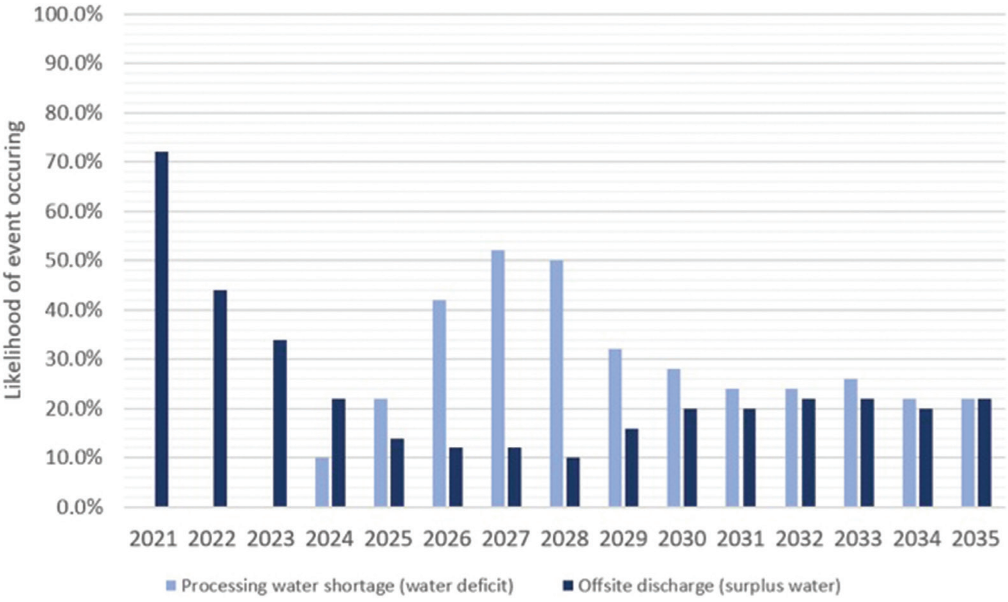

***Figure 2** Modelled water surplus or deficit risk.*

supply or a completely new offsite dam and associated catchment.

The water balance developed previously was used to assess combinations of additional storage and water supply required to mitigate the risk of process water shortages. The outcomes of this modelling are summarised in Table 2. It demonstrates the difference between using a model that only assesses outcomes against a "worst case" scenario versus models that provide probabilistic results and therefore allow for a risk based approach. Under a "worst case" scenario model, the recommendation would be for additional storage in the order of 12 to 20 GL. This is a large storage relative to the mining operations and potential cost prohibitive. Under a probabilistic model, the cost of the additional storage was traded off against the costs of reduced processing due to the water shortages. In this case, a 2 percent annual exceedance probability was determined to provide an optimal balance and lead to the recommendation of additional storage in the order of 6 to 12 GL. This option still exposed the mine operation to approximately 30% likelihood of a year with processing water shortages up to 40% over the remaining mine life but allowed for a significantly smaller storage than that recommended by the "worst case" scenario and avoided unnecessary overdesign and the associated costs for the mine operator.

In summary, Case Study 2 has demonstrated how an Integrated Water Management model coupled with probabilistic climate inputs delivers critical and actionable information on the mine's MWMS including:

- **What** – significant water surplus and deficit risks
- **Where** – storage capacity constraint
- **When** – immediately for water surplus and in 3-4 years for water deficits
- **Likelihood** – 10% to 70% for water surplus events and 0% to 50% for water deficit events
- **Impact** –ore processing capacity (and therefore mine revenue)
- **Magnitude** – up to 40% of ore processing capacity lost

Through the understanding of all these issues, a solution that was optimised for both cost and risk to the miner was able to be achieved. This would not have been the case if simpler modelling techniques were used. It should be noted that this method only provides an estimate for the magnitude of the additional storage volume required and that outcomes can vary significantly depending on the quality and reliability of the inputs and assumptions the model is based on. These models also tend to become less reliable the further one attempts to forecast into the future. These factors should not be discounted when interpreting results.

Conclusions

Through the two case studies covering a range of production scales in both underground and open cut operations and throughout the mine life cycle, the authors of this paper have demonstrated how an Integrated Water Management model approach provides an improved mine resilience tool for identifying MWMS risks and then providing solutions that are timing, cost and impact optimised. The complexity of the multidisciplinary inputs to the these models is there main limitation compared to simpler techniques, which requires an integrated systems thinking in planning and development.

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Table 2 *Additional storage volumes and water supply required to mitigate process water shortages.*

Average annual additional water supply provided	Size of additional storage required – under "worst case" conditions	Size of additional storage required – under 2 percent exceedance conditions	Size of additional storage required – under 5 percent exceedance conditions
500 ML/year	≈20.0 GL	≈12.0 GL	≈6.5 GL
1000 ML/year	≈12.0 GL	≈6.0 GL	≈4.5 GL

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