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# The utility of a systems approach for managing strategic water risks at a mine site level

N.C. Kunz*, C.J. Moran

*Sustainable Minerals Institute, The University of Queensland, St. Lucia, Queensland 4072, Australia*

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ABSTRACT

Mining operations increasingly encounter two water-related risks: (1) *Dryness* – having insufficient water to meet production needs; and (2) *Wetness* – having too much water leading to discharge during high rainfall events. Water accounts and dynamic systems models have been developed to assist decision makers in identifying these risks, however little empirical research has explored the practical utility of a systems modelling approach. To address this gap, we apply a systems approach at an operational mine site. Uncertainties in water flows were identified to guide decisions about where additional monitoring equipment should be installed to improve the accuracy of the overall site water balance. Simulation results provided valuable information for the site water committee to consider "out-of-the-box" ideas for progressing towards its ambitious water goals and mitigating strategic water risks. It is concluded that systems approaches should be further applied within mining and other industrial sectors.



## 1. Introduction

Mining and minerals operations can have detrimental impacts on water resources including long-term changes to water quality and sometimes permanent changes to groundwater levels [1]. These and related water impacts represent significant business risks, leading many companies to develop targets to minimise the quantity of water extracted from the environment and to avoid the discharge of contaminated water [2,24].

Two of the most pressing strategic water risks encountered at a mine site level are those of Wetness and Dryness [7]. Wetness risk occurs when the stock of water on a site exceeds its carrying capacity, resulting in flooding (with associated environmental impacts due to the discharge of contaminated water). Dryness risk occurs when there is insufficient water available for production and/or when the site's use of water creates conflicts over water access for surrounding communities. Both of these risks represent very real concerns for mining companies and have been well documented in both developed [7,19] and developing [17] contexts.

Managing the risks of Dryness and Wetness can be difficult in practice due to the complexity of the mine site water balance [20]. Many mining operations span across large geographical areas, comprising of several storage dams connected through a complex web of infrastructure. Rainfall and runoff can represent large inputs to the site such that gaining an understanding of water movement requires knowledge of the local hydrology. Managing strategic risks is also complicated by the divisional management structures that characterize many mining operations [5]. Managers generally have a good understanding of how water is used within their department (e.g. mining) but have little understanding of how water quality and quantity might impact upstream/downstream components of the production chain (e.g. processing).

Two approaches can assist mine site decision makers in better understanding their water-related risks. The first is through the development of water accounts to track the flows of water to, from and within the mine lease boundary [8]. The data collected during water accounting can then be used as an input to corporate sustainability reports, and for water reporting frameworks such as water footprint [29] and GRI [15]. Such information is crucial for benchmarking water performance across sites, but can also facilitate decision making at a site level through highlighting which water sources the site is most dependent on. The second approach is through the development of dynamic systems models that simulate flows throughout the mining site allowing assessment of Wetness and Dryness risks associated with climatic variations [7]. Although there is growing attention on the use of systems models within the mining industry [14,16,7], research has largely focused on developing and validating the modelling approach. With the exception of [5], there has been considerably less attention on the utility of systems models for facilitating strategic decision making at a mine site level.

In this article, a detailed empirical case study is used to explore the utility of a systems approach for engaging senior managers in a

* Corresponding author.
*E-mail address:* nadjakunz1@gmail.com (N.C. Kunz).

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conversation about strategic water risks. After describing the case study site, a water account is developed to describe the main flows of water to/from the mining lease. A dynamic systems model is then developed to identify strategic risks with respect to Wetness and Dryness. The discussion describes the experiences of applying the model at the case study site, and explores opportunities for future research.

## 2. Material and methods

### 2.1. Case study description

The case study is a minerals site operating in Australia. It is located in a high rainfall environment, averaging 631 mm/year from 1961 to 1990 compared with the Australian average of 472 mm/year over the same period [23]. Rainfall is seasonal, dominantly falling during the summer months from December to February. Achieving responsible water stewardship was a strategic priority for the management team – the mine is located in an environmentally pristine region and water has strong cultural value to the local indigenous community. Prior to commencing our research, the site had already achieved significant reductions in the amount of freshwater imported to site; however the management team had set ambitious targets to further reduce freshwater use, to minimise off-lease discharge, and to maximise the efficiency of water use across the production chain. In progressing towards these targets, the site HSE manager sought "out-of-the-box" ideas for how the site could strive towards achieving these targets.

Despite considerable internal documentation relating to water, many employees perceived the site water system to be complicated. Different departments held different models for addressing water issues within their area of accountability; including a model to predict water shortages within the processing plant, a model to predict hydrogeological movement within the underground mine, and a model to optimise water inventories across all pumps, pipes and storage dams on the site. However these models were all managed separately and were at a level of detail that did not facilitate conversation across departments about strategic water risks arising at a site level.

This lack of understanding about the overall water system posed a challenge for identifying "out-of-the-box" ideas that the HSE manager was hoping for. In March 2010, the site general manager established a water committee to drive improvements in water management practices and the committee met regularly until November 2010. However an analysis of the committee's activities [20] found that it was operating with moderate success, and that there was a tendency to focus on tactical day-to-day issues rather than the strategic priorities for which it had been established.

It was theorized that a systems model would be appropriate for assisting the water committee in working towards its ambitious goals, and for improving general understanding about water among employees across the site. Four site visits were conducted over the course of the project [20]; most data for the site water balance were collected during the first and second site visits (spanning one week and four weeks respectively). Results were communicated and validated throughout the full project.

### 2.2. A static representation of the site water system and a water account

A static representation of the site water system was developed to represent the main flows of water around the site during the 2010 reporting period, and a water account was used to summarise the overall inputs and outputs to/from site. The adopted notation is consistent with established definitions used in water accounting for mine sites [6]:

- *Input:* A volume of water (of high or low quality) received by the operational facility, or that becomes available from within the operational facility (e.g. aquifer inflow)
- *Output:* A volume of water (of high or low quality) that is removed from the operational facility
- *Store:* A facility that holds and/or captures water
- *Task:* Describes the uses to which water is put in an operation (e.g. mining, processing)
- *Raw water:* Water that has not previously been used by any tasks
- *Worked water:* Water that has passed through a task at least once

### 2.3. Quantification of water flows

Data were sourced from site documentation, with the exception of rainfall, runoff, evaporation and seepage. Evapotranspiration rates were sourced from the Australian Bureau of Meteorology SILO database [10], using the geographical coordinates for the case study site as determined from the Data and Software Centre for the Department of Mines and Petroleum [9] and confirmed using Google Earth. The rainfall intercepted by stores was estimated by multiplying the rainfall rate by the surface area. Evaporation was modelled using an analogous approach except that a correction factor was applied because actual evaporation from storage dams is typically lower than that measured by pan evaporation [7]. A factor of 0.9 was selected during model calibration. Runoff flows were simulated using the Australian Water Balance Model (AWBM) [3] within the Rainfall Runoff Library of the eWater toolkit [13]. Seepage from unlined stores was not directly measured and a notional minimal rate of water loss was estimated at 0.00014 fraction/day as per Silvester [25]. A full list of the raw inputs to the model are provided in Supplementary Data.

### 2.4. Towards a dynamic systems model

A dynamic model was developed following the approach of Cote et al. [7]. For the static water account, a period of one year was appropriate because the aim was to provide a snapshot of how water was used in a way that would help employees conceptualise the main flows in/out of the water system. However the aim of the dynamic model is to evaluate risk. Thus, the model considers the largest source of variation that may contribute to water-related risks. In this context, this is the climate. The temporal boundary was thus increased to encompass the full period for which climate data are available (spanning 1889–2012).

All flows within the water circuit were modelled to be the same at each time step over the simulation period (123 years), with the exception of rainfall, evaporation and runoff which were varied on a daily basis. The model therefore evaluates the risk of the site operating with its current configuration in terms of a statistical view based on long term climate history. The dynamic model was calibrated and validated (see Supplementary Data), and results were used to engage site decision makers in a conversation about strategic water-related risks.

## 3. Results

### Systems representation of the site water system and a water account

The site's detailed water circuit diagram was aggregated into a