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

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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

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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

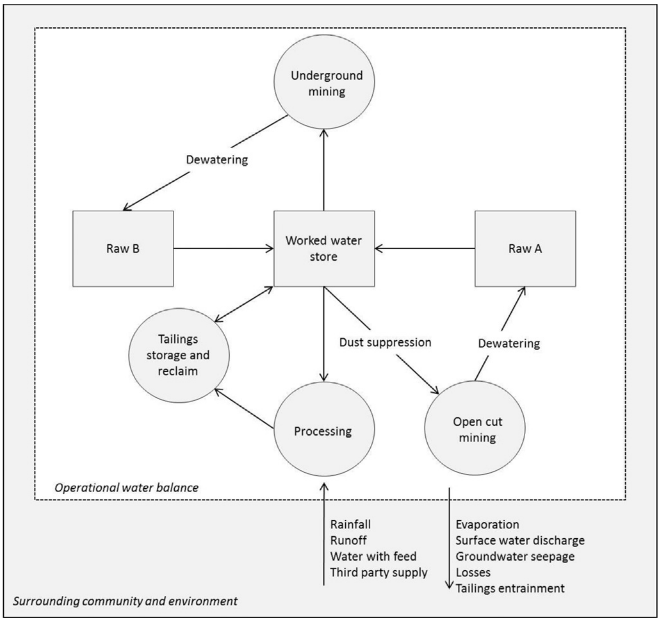

Fig. 1. A systems representation of the mine site water balance. Stores are represented as rectangles; tasks are represented as circles.

systems representation (Fig. 1). Individual water storage dams with common characteristics were combined to represent a single store, while individual unit operations were combined into tasks. The resultant model includes three notional water stores that represented three levels of water quality (two raw water stores and one worked water store). Four tasks are represented: a processing plant, underground mining, open cut mining, and potable water treatment/use. Multiple tailings dams were aggregated into a single tailings storage function. Water inputs consist of rainfall, runoff, entrainment in the feed ore, and aquifer inflows intercepted from the open cut and underground mine. Water outputs include evaporation, discharge to surface and groundwater, entrainment in tailings, and miscellaneous losses.

A water account (Table 1) was developed to represent the overall movement to/from the operation. Reviewing the inputs indicates the main sources of water and thus the vulnerabilities that could be faced if these flows were to change. The site is relatively self-sufficient in its water supply, with minimal water (~1%) being sourced from third-party suppliers. This puts it in a good position compared with sites that may be exposed to reductions in water allocation from third-party suppliers [27]. However the systems view highlights a different risk, i.e. ~40% of overall inputs are from rainfall/runoff. Exposure to a year of unusually low rainfall may therefore compromise the water supply required for operations. Developing strategies to increase resilience to variations in climate patterns is therefore important.

Reviewing the overall outputs reveals where water is lost from the system, and thus points to opportunities to save water. A significant percentage of water is lost to evaporation (~50%) and off-site discharge (~20%). The site may thus consider projects that reduce evaporation losses or to capture and recover water that would otherwise be discharged to surface or groundwater.

3.1. Dynamic systems model

Following the approach of Cote et al. [7], likelihood plots were derived for each of the three water stores (Fig. 2) indicating the proportion of time (over the 123 year simulation period) that each store would exceed a certain threshold.

Table 1
Overall inputs and outputs to/from site during the 2010 reporting year as presented during the second field visit to site. Asterisk indicates simulated or estimated values.

Overall inputs to site (based on 2010 data)			
	Volume (ML/yr)	**Total input (%)**	**Certainty**
UG mine dewatering	3480	40%	High
**Runoff*	2376	27%	Low
**Rainfall Intercepted*	1428	17%	High
AK1 bores	624	7%	High
AK1 sumps	324	4%	High
Entrained in feed ore	324	4%	High
Third party supply (from lake)	60	1%	High
Total	**8616**		
Overall outputs from site (based on 2010 data)			
	Volume (ML/yr)	**Total output (%)**	**Certainty**
**Evaporation (Storage dams)*	2802	30%	Low
Evaporation (Dust suppression)	1908	20%	Low
Discharge via process plant sump	1824	19%	Low
Overflow from main storage dam	Unknown	Unknown	Low
Entrained in fine tails	1152	12%	Medium
Potable water users	540	6%	High
Loss (UG water use)	456	5%	High
Entrained in coarse tails	420	4%	High
**Seepage*	288	3%	Low
Direct discharge to Creek	84	1%	Medium
Total	**9474**		

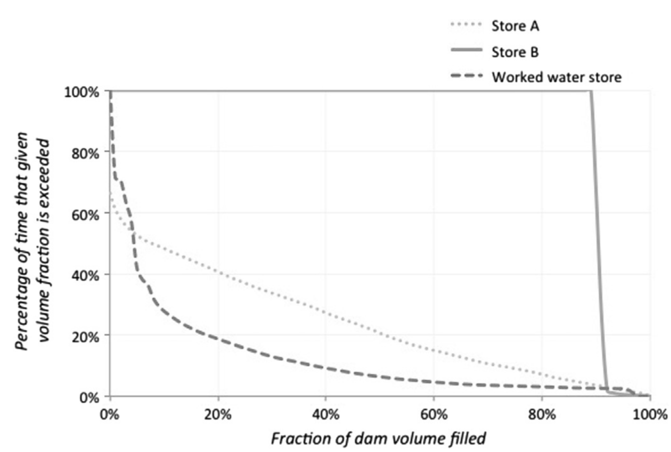

Fig. 2. Likelihood plots for each water store represented in the model. Each plot represents the percentage of time (over the simulation period) that each storage dam would be above a certain threshold.

To quantify risk, likelihood plots were combined with a definition of consequence. The constraints of Cote et al. [7] were adopted wherein a high level of consequence occurs when a store drops below 25% full (too little water – "dryness") or exceeds 90% full (too much water – "wetness"). These constraints are hereafter referred to as the Dryness Index and Wetness Index. Table 1 shows the simulation results which reveal that several stores risk having too little water.

The dryness and wetness indices for the tailing storage facility were calculated at 96% and 0% respectively. This is within an acceptable range because excess water in tailings dams can compromise stability of the dam wall [28].

Table 2
Wetness and dryness indices. Dryness Index refers to the proportion of time (over the 123 year simulation period) that a store is below 25% full. Wetness Index refers to the proportion of time that a store is above 90% full.

	Dryness index	Wetness index	Overflow volume (ML/year)
Raw A	63%	4%	542
Raw B	0%	45%	1
Worked water store	84%	4%	0

4. Discussion: the utility of the systems modelling approach

4.1. The systems model as a "boundary object"

The results of the static water account and preliminary results from dynamic modelling were presented to the site leadership team comprised of managers, superintendents and engineers/technicians. The systems approach was effective at initiating conversations across diverse actors about how to best manage water risks. In this way, the systems model acted as what Starr [26] termed a "boundary object" which provide a means to "*mediate interactions between different communities of practice by providing a common basis for conversations about solutions to problems*" [12]. Carlile [4] suggested that a "good" boundary object satisfies three characteristics: (1) it provides a shared language for individuals to represent their knowledge, (2) it allows individuals to understand their differences and dependencies across a given boundary, and (3) it facilitates joint transformation of knowledge.

The systems approach satisfied the first criteria by providing a shared language for individuals to represent their knowledge: the language of risk is a term with which managers are intimately familiar and our experience found that this was effective at focusing attention on strategic issues which jointly affected different areas of the site. Second, the model allowed individuals to understand their high-level dependencies between stages of the production process. Finally, it facilitated joint transformation of knowledge: the model stimulated discussion about innovative solutions for mitigating strategic water risks.

The use of a systems model as a boundary object is significant because recent research has highlighted that a lack of strategic thinking at a mine site level has contributed to decreased productivity [22]. One site representative commented that the work had guided them to "*ask the right questions*", and that the model had been "*… really helpful at getting managers and superintendents on board-they can see the big picture… Knowing that it's not complicated but sometimes its complex to understand.*" This work therefore provides support for further development of systems models for improving strategic decision making within the mining industry.

4.2. Improving the accuracy of the site water balance

To facilitate decision making about which water projects to invest in, it is crucial that site decision makers are working from an accurate water balance whereby there is high certainty over the most significant flows. "Significant" flows are defined as those with large volumes and thus represent a large proportion of the overall movement of water throughout site. "Uncertain" flows are defined as those that over which there is low confidence in their accuracy. Several significant and uncertain flows were identified during this research including the evaporative water losses from site storages and from dust suppression, the discharge of water via the process plant sump, and overflow from the main storage dam, the moisture content in the tailings slurry exiting the processing plant, and the quantity of make-up water to the processing plant.

There was also high uncertainty regarding the quantity of water being received to site via runoff. The operational water balance had estimated the runoff to site using a rainfall/runoff simulation model which had not been validated. This finding was particularly troubling given that runoff represented ~30% of the overall inputs to site and inaccuracies in this value could impede the ability to accurately assess risks associated with long term water supply security. Ongoing research work is consequently underway to gain more accurate runoff estimates for mine site water balances [18].

The uncertainties in the water balance were communicated to the site water specialist who was reviewing the accuracy of an operational water balance model for day-to-day monitoring. Interestingly, she had identified a similar set of parameters. The identification of the same uncertainties using two different approaches (bottom-up and top-down) provided confidence that the most important parameters had been identified. However, there are two advantages with our top-down (systems) approach. First, it provided a faster way to identify the most significant flows because we identified the same parameters but with less knowledge about the details of the site water system. Second, the representation of the water balance at a systems scale facilitated communication with the management team about why investments should be made (e.g. additional monitoring) to gain greater accuracy over significant and uncertain flows. This business case was more difficult to communicate using the operational (bottom-up) model because its high level of detail tended to overwhelm managers.

4.3. "Out-of-the-box" ideas for meeting water goals

A priority for the site HSE manager was to identify "out-of-the-box" ideas that could assist the site in progressing further towards its ambitious water goals. The results revealed that two stores (Raw A and Worked Water Store) were at risk of having too little water, and all stores were at a small risk of discharging water. The next step for the site management team is to evaluate management options for mitigating these risks. Three basic types were identified during this research (Fig. 3). *Operational Solutions* involve a change in management practices and are the least costly; for example, the site could become more effective at pumping water between storage dams to prevent overflow or could implement improved store control to reduce evaporation. *Technological Solutions* involve incorporating new equipment or products; for example, the site could consider implementing a new process control system to automatically redistribute water between storages. In some cases, there may not be sufficient pumping capacity to transport water in the volumes required to optimise site storages. In these cases, *Infrastructure Solutions* would be required to change the site's configuration.

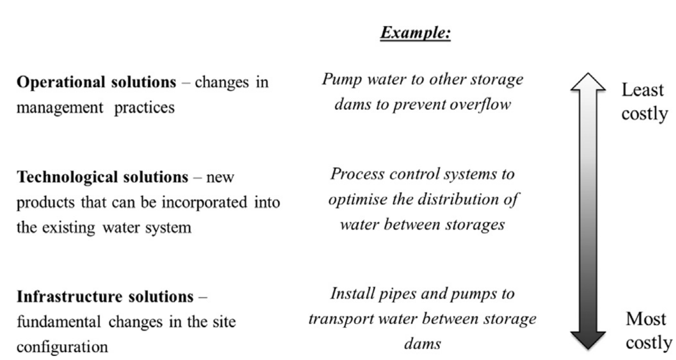

Fig. 3. Example of different solutions to improve water management on mining sites.

Having decided which options to consider, the dynamic systems model offers a starting point for the site water committee to evaluate management options and to decide which projects to invest in. Discussion topics should include:

- Is the current site configuration accurate? Could additional monitoring be implemented to further improve confidence over significant and uncertain flows?
- How is the site configuration likely to change over the long term and how might this impact the risk profile?
- What is the financial cost associated with having too much or too little water in each storage dam?
- Which Management Options are the most cost effective?
- Which additional Management Options might be considered?

4.4. The systems model as a communication tool

A further benefit of the static water account was that it provided a framework for communicating water-related information to employees and interested stakeholders. When we first engaged with the case study site, employees commented on the complicated nature of the site water system. While most employees were familiar with how water was used within their area of responsibility, they did not have a good understanding of how water moved elsewhere around site, nor did they grasp the interdependencies between the various water tasks and stores. The site Health, Safety and Environment department sought to represent the water system in a simplified format that would facilitate understanding about how water was used. The static representation of the water balance provided an appropriate framework. Results were displayed on posters within each department which also provided general information about the research project and explained why a water balance was an important step towards improving water management. During a subsequent site visit, employees remarked that the poster had stimulated interest among employees about how water was used. One person suggested that it could be a useful representation to explain the water system to new employees during site inductions.

4.5. Opportunities for future research

An exciting direction for future research is to link the wetness and dryness indices with estimates of the associated financial cost. For example, in Australia some mines have been threatened with production losses due to water shortages during drought conditions [27], while others have faced billion-dollar production losses due to excess water in flood events [11]. The development of such a risk-based approach could follow that of Liu et al. [21] who linked variations in water quality with impacts on flotation recovery.

It is recommended that the financial costs of water shortage and excess be evaluated specifically for the site in question through collaboration with the management team. Different consequence thresholds should also be defined depending on the store. In this paper it was assumed that consequence of wetness and dryness risk is equivalent for all three storages which is not strictly true. For example, Raw B receives runoff water from the waste rock dump and the risk of this dam overflowing represents a compliance issue which is not the case for overflow from Raw A. Conversely, Raw A has the largest capacity at 6370 ML (compared with 184 ML and 220 ML for Raw A and the Worked Water Store, respectively) and is the main source of water for operations; low water levels thus represent a threat to production.

5. Conclusions

Although many models exist to inform decision making regarding water issues on mining sites, the majority are not well suited to addressing the strategic objectives relevant to mine managers. This paper has explored the potential of a systems modelling approach to address this gap. Prior to undertaking this research project, the case study site already had an operational water balance model that was used by the site water specialist. However this model proved too detailed for managers to engage with, resulting in a general lack of understanding about the overall movement of water across site and a perception that the water balance was complicated. The development of a static water account and a dynamic systems model provided an appropriate level of detail for managers to understand and evaluate options for addressing the two strategic risks of most concern at the site – too much or too little water. Systems approaches of this kind may also have valuable application in the broader industrial sector.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.wri.2016.02.001.

References

[1] J.M. Amezaga, T.S. Rotting, P.L. Younger, R.W. Nairn, A.J. Noles, R. Oyarzun, J. Quintanilla, A rich vein? Mining and the pursuit of sustainability, Environ. Sci. Technol. 45 (1) (2011) 21–26.
[2] BHP Billiton, We value sustainability, 2012 BHP Billiton Sustainability Report, BHP Billiton, Melbourne, VIC, 2012.
[3] W. Boughton, The australian water balance model, Environ. Model. Softw. 19 (10) (2004) 943–956.
[4] P.R. Carlile, A pragmatic view of knowledge and boundaries: Boundary objects in new product development, Organ. Sci. 13 (4) (2002) 442–455.
[5] C. Côte, C.J. Moran, O.J. Acosta, Progressing towards sustainability: from water efficiency to water effectiveness at the collahuasi mine, In: J. Wiertz. (Ed.), Water in Mining-2nd International Congress on Water Management in the Mining Industry (WIM 2010), Gecamin Santiago, Chile, 2010.
[6] C.M. Cote, J. Cummings, C.J. Moran, K. Ringwood, Water accounting in mining and minerals processing. In: J.M. Godfrey K. Chalmers. (Eds.), Water accounting: International approaches to policy and decision-making, Edward Elgar Cheltenham, United Kingdom, 2012.
[7] C.M. Côte, C.J. Moran, C.J. Hedemann, C. Koch, Systems modelling for effective mine water management, Environ. Model. Softw. 25 (12) (2010) 1664–1671.
[8] A.N. Danoucaras, A.P. Woodley, C.J. Moran, The robustness of mine water accounting over a range of operating contexts and commodities, J. Clean. Prod. 84 (0) (2014) 727–735.
[9] Department of Mines and Petroleum, Operating mines, Government of Western, 2012 Australia at: ⟨http://geodownloads.dmp.wa.gov.au/⟩ (accessed 9.07.12).
[10] Department of Resources Energy and Tourism, Water management-leading practice sustainable development program for the mining industry, Commonwealth of Australia, Canberra, 2008 ⟨http://www.ret.gov.au/resources/documents/lpsdp/lpsdp-waterhandbook.pdf⟩ (accessed 22.5.13).
[11] J. Devine, High costs of floods confirmed, 2011 ⟨https://www.qrc.org.au/01_cms/details.asp?ID=2835⟩ (accessed 13.04.12).
[12] M. Dodgson, D.M. Gann, A. Salter, In case of fire, please use the elevator: simulation technology and organization in fire engineering, Organ. Sci. 18 (5) (2007) 849–864.
[13] Rainfall runoff library. eWater CRC, Innovation Centre, University of Canberra, Canberra, 2013 ⟨http://toolkit.net.au/Tools/RRL⟩.

[14] L. Gao, D. Barrett, Y. Chen, M. Zhou, S. Cuddy, Z. Paydar, L. Renzullo, A systems model combining process-based simulation and multi-objective optimisation for strategic management of mine water, Environ. Model. Softw. 60 (0) (2014) 250–264.
[15] Global Reporting Initiative, Sustainability reporting guidelines & mining and metals sector supplement, RG Version 3.0/MMSS Final Version, Global Reporting Initiative, Amsterdam, 2011.
[16] A.J. Gunson, B. Klein, M. Veiga, S. Dunbar, Reducing mine water requirements, J. Clean. Prod. 21 (1) (2012) 71–82.
[17] D. Kemp, C.J. Bond, D.M. Franks, C. Côte, Mining, water and human rights: making the connection, J. Clean. Prod. 18 (15) (2010) 1553–1562.
[18] N.C. Kunz, A.W. Woodley, Improving the accuracy of mine site water balances through improved estimation of runoff volumes, Water in Mining, AusIMM, Brisbane, Australia, 2013.
[19] N.C. Kunz, C.J. Moran, Sharing the benefits from water as a new approach to regional water targets for mining companies, J. Clean. Prod. 84 (2014) 469–474.
[20] N.C. Kunz, C.J. Moran, T. Kastelle, Implementing an integrated approach to water management by matching problem complexity with management responses: a case study of a mine site water committee, J. Clean. Prod. 52 (0) (2013) 362–373.
[21] W. Liu, C.J. Moran, S. Vink, Quantitative risk-based approach for improving water quality management in mining, Environ. Sci. Technol. 45 (17) (2011) 7459–7464.
[22] P. Mitchell, M. Bradbrook, L. Higgens, J. Steen, C. Henderson, T. Kastelle, C. Moran, S. Macaulay, N. Kunz. Productivity in mining: now comes the hard part, a global survey EYGM Limited, 2014.
[23] National Water Commission. Rainfall distribution Australian Water Resources 2005: Australian Government 2007.
[24] Rio Tinto, Water, 2013 ⟨http://www.riotinto.com/sustainabledevelopment2012/environment/water.html⟩, (accessed 20.11.14).
[25] N. Silvester, Appendix d: Waterminer user manual Centre for Water in the Minerals Industry, 2006 ⟨http://www.acarp.com.au/abstracts.aspx?repId=C15001⟩, (accessed 22.5.13).
[26] S.L. Starr, The structure of ill-structured solutions: Boundary objects and heterogeneous distributed problem solving, in: M. Huhns, L. Gasser (Eds.), Readings in Distributed Artificial Intelligence,, Menlo Park, CA: Morgan Kaufman, 1989.
[27] H.D.J. Stegink, J. Lane, D.J. Barker, B. Pei, Water usage reductions at queensland alumina, Paper presented at Water in Mining 2003, Brisbane, 2003.
[28] Sustainable Minerals Institute and the Minerals Council of Australia. Water accounting framework for the minerals industry-user guide version 1.2, 2012, April. ⟨http://www.minerals.org.au/file_upload/files/resources/water_accounting/WAF_UserGuide_v1.2.pdf⟩ (accessed 20.01.13).
[29] G.P. Zhang, A.Y. Hoekstra, R.E. Mathews, Water footprint assessment (WFA) for better water governance and sustainable development, Water Resourc. Ind. 1–2 (0) (2013) 1–6.