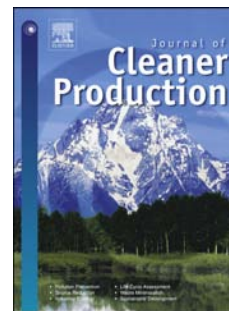


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Sharing the benefits from water as a new approach to regional water targets for mining companies

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Article Title: Sharing the benefits from water as a new approach to regional water targets for mining companies

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Keywords: *Mining, water management, sustainability, sustainable development, risk, water benefit, environmental and social trade-offs.*

Abstract:

Most major mining companies have articulated strategies and targets to minimise the impacts of operations on surface and groundwater resources. However, the focus tends to be on mitigating negative impacts. In this field note, we make two contributions to assist mining sites in playing a positive role in implementing Integrated Water Resources Management (IWRM) aspirations. First, we introduce the notion of “water benefits” as a pathway for operationalizing regional IWRM objectives at a mine site level. Second, we propose a decision making framework to facilitate investment in water benefits. The framework comprises of five steps: (1) Select system boundary wherein benefits are to be delivered; (2) Quantify water availability; (3) Determine potential benefits; (4) Identify acceptable benefits; and (5) Implementation and monitoring. For a site to deliver water benefits that extend beyond the legal obligation of the company, we contend that there must be a sound business case. We therefore distinguish between steps that should be decided by the business (steps 1, 2 and 4) from those that should be completed in collaboration with the broader community (steps 3 and 5).

Within this field note we do not test the practical utility of the framework in an empirical setting and as such it is not intended to be prescriptive. Rather, we seek to provide a foundation for scholarly/industry debate about how decision makers at a mine site level could take a more active role in contributing towards IWRM aspirations. We conclude that a “water benefits” perspective offers a novel basis for establishing regional water targets and could serve numerous advantages at a site-level including improved recognition about the value of water and improved understanding and mitigation of strategic water-related risks.

Key words (indexing terms): water management, sustainability, risk, water benefit, environmental and social trade-offs.

1. Introduction

Over the last several decades, many governments have embraced the concept of Integrated Water Resources Management (IWRM) in an effort to balance water allocation across competing social, environment and economic demands (Abdalla, 2008; Abdullaev et al., 2009). Private industry is recognised as an important player in this process through making “*technological, production and consumption choices based on the real value of water and the need to sustain the natural resource assets over time...*” (GWP-TAC, 2000). While most would agree that this is a desirable aspiration, there is little guidance available to assist industrial sites in operationalizing such a concept in practice. The broader literature on IWRM provides little further insight – the concept has been criticised for its ambiguous terminology (Biswas, 2008; Hering and Ingold, 2012) and a lack of supporting metrics and analytical frameworks (Jeffrey and Gearey, 2006). The purpose of this field note is to consider how mining companies might take a more active role in contributing towards IWRM aspirations.

Traditionally, it has generally been accepted that the appropriate level of involvement by the private sector in broad issues of water allocation is via water markets where they exist and in direct negotiation with governments to secure access to water otherwise. However in recent years the industrial sector in general, and the mining industry in particular, has actively sought to demonstrate responsible water stewardship (Moran, 2006). Most major mining companies have committed to sustainability principles and set performance targets in many areas, including water (ICMM, 2006; Minerals Council of Australia, 2005). While significant reductions in water consumption have been achieved, most efforts have focused on reducing the water used for specific tasks and on reusing water within mining leases. There is growing pressure on companies to think beyond the bounds of their own operations and to consider water-related impacts at regional scales (Barrett, 2009; Kemp et al., 2010; Moran et al., 2008; Moran, 2006).

In many parts of the world, mining, minerals and energy supply networks play an important role in IWRM implementation. Operations can impose long term and sometimes permanent impacts on water resources (Amezaga et al., 2011), thereby impeding accessibility for future generations. This is especially controversial when resource deposits are located in water scarce, environmentally sensitive or culturally sensitive regions. Water access by mining companies can also be controversial when the communities surrounding operations do not themselves have adequate access to freshwater to meet human rights (Kemp et al., 2010). The cumulative impacts of multiple mines operating within one region is also becoming increasingly evident (Franks et al., 2013)– the expanding coal seam gas industry in Queensland, Australia and the shale gas industry in the USA are examples wherein the water-related impacts of one company cannot be assessed in isolation.

While the importance of the aforementioned issues is gaining some acknowledgement by the International Council on Mining and Metals (ICMM, 2012, 2013) and likely by implication in corporate offices of major mining companies, there can be a disconnect between corporate water strategies and implementation at a site level (Ringwood, 2006). Practical tools and decision making frameworks are thus needed to assist mine site managers in conceptualising the importance of water within their operating context and to actively contribute towards maximising the benefits provided by water.

In this paper, we make two contributions towards this quest. First, we introduce the notion of “water benefits” as a pathway for operationalizing regional IWRM objectives at a mine site level. Second, we propose a practical framework that a decision maker, such as a mine site manager, might use to decide whether/how to invest in water benefits. Our framework is not intended to be

prescriptive, but rather to provide a foundation for scholarly/industry debate and discussion about concepts, metrics and tools that require development in future research.

2. Defining water benefits

Moran et al. (2004) used the concept of water benefits to refer to the ways in which water use can promote or diminish wellbeing. Benefits may include health, wealth, prestige and social identity, social cohesion, recreation, aesthetics, moral and cultural, spiritual (Syme et al., 2008). However water can also provide environmental and economic benefits for which the direct contribution to human wellbeing may not be obvious. It could also be argued that all water benefits are positive, and that the challenge lies in evaluating the trade-offs between competing benefits. We therefore redefine water benefits as “*the ways in which water use promotes human wellbeing, environmental pristineness, or economic outcomes*”. When comparing the potential benefits that water can provide, it should be recognised that the same volume of water can serve multiple benefits across the water cycle because (provided that water quality constraints are satisfied) the use of water for one purpose does not preclude its use for another (Syme and Nancarrow, 2008). In other words, water can satisfy both consumptive and non-consumptive uses (Liu et al., 2009).

Encouraging decision makers at a mine-site level to recognise water from a “water benefits” perspective might contribute towards delivering the greatest value from water in a regional context. A challenge is that once a company has secured access to water through its operating license, it typically has no legal obligation to deliver benefits beyond its own economic endeavours. In Australia for example, industrial operations typically access water via a water license from regulatory authorities, which stipulates the maximum quantity of surface/groundwater that can be extracted. Historically, mining sites have been able to access water at a relatively low cost compared with the overall costs of production (Ringwood, 2006). Further, some sites operate under “take-or-pay” contracts, which require a minimum payment for water use regardless of the amount of water which is actually extracted (Corder and Moran, 2006). This provides little financial incentive for sites to minimise the amount of water that they extract, because the only cost that is saved is that associated with water in use, e.g. pumping.

To overcome this issue, we contend that a process is needed to justify the “business case” for a mine site manager to contribute towards water benefits. In the following section, we present a preliminary decision making framework to work towards this aspiration, and describe analytical tools and models that may assist.

3. Towards a framework for sharing water benefits

The framework (Figure 1) aims to provide a site decision maker with a means of comparing the business risks (and costs) of making a portion of a site’s water allocation available to provide social and environmental benefits, against the value (rewards) that this water could deliver. The approach consists of five steps. We distinguish business decisions that should be made within the company from active community engagement processes.

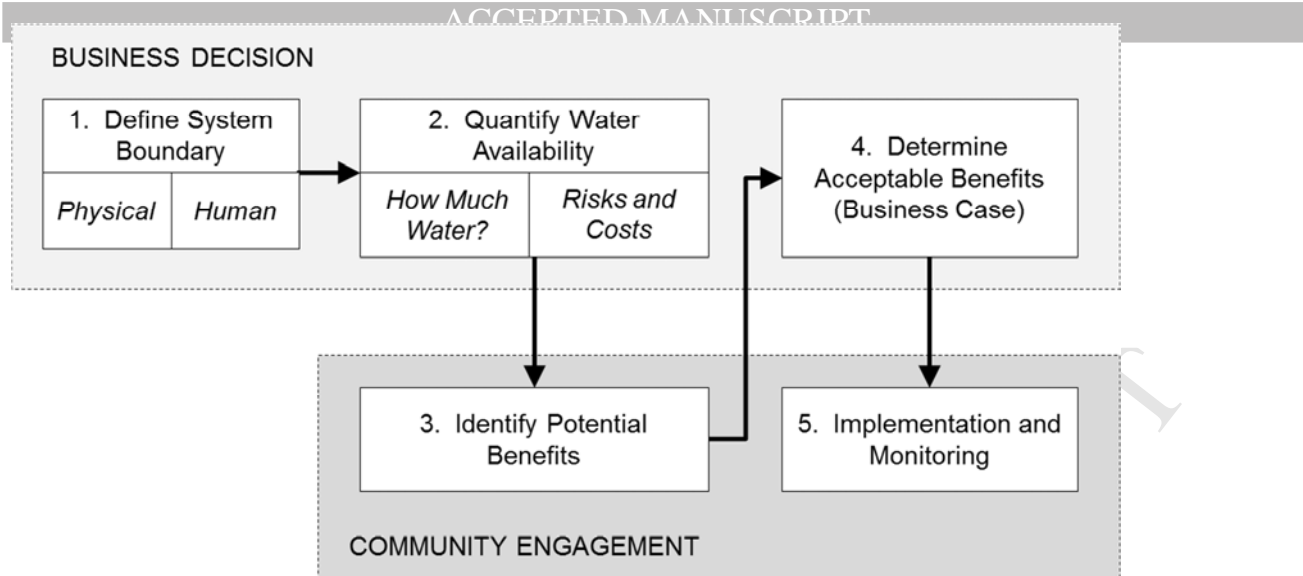


Figure 1. Framework to facilitate decision making by a mine site manager regarding the risks (costs) and benefits (rewards) of reallocating water for sustainability benefits

Step 1. *Define System Boundary*

A system boundary must first be defined wherein water management efforts are to be focussed. This boundary should consider both physical and human dimensions because both are important for progressing towards sustainability (Kunz et al., 2013).

The physical boundary would typically entail the domain over which the decision maker exercises control or can create sufficient influence; for example, regarding the control of infrastructure to move water to potential uses. In some cases, a decision maker may define a system boundary beyond his/her direct control. For example, Groupe Danone, Nestle and Unilever formed the Sustainable Agriculture Initiative Platform in 2000 to minimise the water used to produce raw materials for their processes (SAI, 2007).

The human boundary should also be defined to identify community members that may derive benefits from water (re-) allocation efforts. For example, in recent work on water infrastructure supply networks, Lienert et al. (2013) demonstrated how a formal stakeholder analysis can be combined with social network analysis to identify influential stakeholder groups and understand their perceptions. Such an approach may also have utility in the resources industry, particularly when views are divergent and relationships complex; for example, the expanding coal seam gas industry in Queensland, Australia.

Step 2. *Quantify Water Availability*

To decide whether the benefits of reallocating some water outweigh the risks, the decision maker must understand how much water can be made available, by what mechanisms and at what cost.

Two strategic risks can arise in relation to the (mis-) management of water storage volumes on a mining site: (1) water shortage (Dryness), and (2) water discharge (Wetness) (Côte et al., 2010b). In Australia, these risks are all too real for some mining sites – climatic variability over the last decades has contributed to water supply security risks during drought conditions (Stegink, 2003) and billion-dollar production losses due to excess water in flood events (Devine, 2011). A manager must thus be convinced that exposure to these risks will not increase through the reallocation of

water beyond the mining lease. This can only be achieved through a sound understanding of the mine site water balance.

Computer models are increasingly used on mining sites for water accounting, reporting on water performance and for facilitating decision making about water-related issues (Côte et al., 2009; Gosling, 2010; Gunson et al., 2012). Cote et al. (2007) develop a systems model that allows direct quantification of the strategic risks of Wetness and Dryness. The model comprises four components (storage facilities; water tasks; a blending facility and a desalination plant) that can be used to describe any mining operation. They simulate the main water flows of water throughout the mining lease on daily timesteps over a long term time period (~100 years) and evaluate risk during different climatic variations. This produces an “exceedance curve” which describes the likelihood that the site will face the risk of Wetness or Dryness. Figure 2 presents a conceptual representation of how different risk profiles can be represented. The y-axis indicates the proportion of time that a given volume fraction is exceeded and thus represents a likelihood function. The x-axis relates to the consequence, however the exact thresholds that define an acceptable level of risk are site- and context- specific.

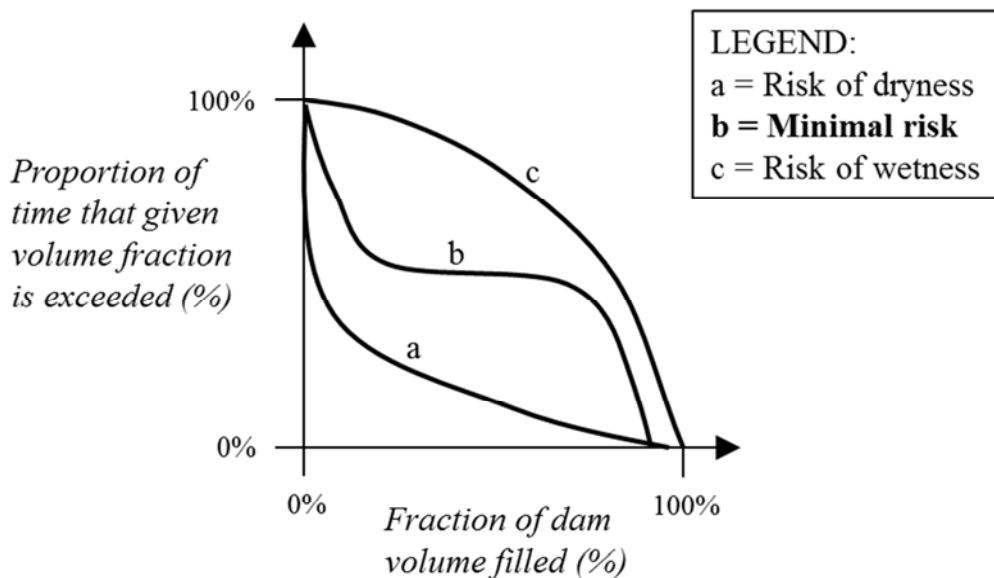


Figure 2. Systems modelling can be used to generate a risk profile for a given mining site. The site water balance is simulated over an extended climatic period to produce an “exceedance curve”. Different risk profiles can then be characterised: (a) a site with a risk of water shortage (Dryness); (c) a site with a risk of discharge (Wetness); and (b) a desirable risk profile. This figure is a conceptual representation based on the model developed by Cote et al. (2007).

Systems models naturally lend themselves to scenario tests, allowing evaluation of how a given risk profile would change through implementing changes to a given site configuration (Côte et al., 2010b). This model type therefore offers an ideal foundation for site decision makers to decide how much water they are willing to make available to deliver water benefits, through evaluating the risks and associated costs.

Step 3. *Identify Potential Benefits*

Once confident about how much water the site is willing to make available, a community engagement process can begin to explore potential social and/or environmental benefits and the quantity of water required to support them.

Social benefits may include the provision of water for amenities such as parks and gardens, sporting fields and swimming pools. The aesthetics of greenery are particularly important in mining communities located in water scarce regions. Investing in water provision for social benefits may make a town more liveable for residents and indirectly influence the retention and attraction of staff, which can represent a significant problem in some mining communities (Brereton et al., 2003). Environmental benefits may accrue by providing water to support biodiversity, e.g. through maintaining minimum flows in rivers systems to meet the needs of local aquatic species. Many mining companies recognise biodiversity management as a component of sustainability performance (Rio Tinto, 2008).

To estimate the quantity of water required to deliver each benefit, an understanding of the local context and climatic conditions is needed. Table 1 provides estimates of the quantity of water required to support various community amenities in the Emerald region, located in the Bowen Basin, Queensland (Australia's largest coal-mining region). These water requirements (maximum 113 ML/year) are all small relative to the amount of water typically used by mine sites in the region (for example, in 2012 the total freshwater use by Rio Tinto's Kestrel mine alone was over 1000 ML/year).

Table 1. Estimates of the amount of water required to support various community amenities in the Emerald region, located in the Bowen Basin, Queensland (refer to Appendix for assumptions)

Community amenity	Water required (ML/year)
For each public playground (of 200m ²)	0.3
For each garden (of 327m ²)	0.4
Football field (6,800m ²)	9
Golf course (85,000m ²)	113
Swimming pool	7.9

This process of identifying potential benefits may generate a list of considerable length. Formal valuation and ranking procedures can assist in prioritising potential water benefits towards highest value uses (Halaburka et al., 2013; Kuosmanen and Kortelainen, 2007).

Step 4. *Determine Acceptable Benefits*

Ultimately, the decision maker must make an assessment as to whether advantages of reallocating a portion of the site's water supply towards "water benefits" outweigh the costs of doing so. The outcomes from the previous stages provide the necessary information to facilitate this decision. A clear articulation of the business case must be made whereby the risks of making water available (in terms of the change to the site water balance profile – i.e. as quantified during Step 2) and any associated costs of water provision are compared against the benefits that the water could provide.

This assessment should be made through internal company procedures, however Moran et al. (2008) provide some insights about how such a process might be envisaged using a water values/risk method. They present a conceptual framework that can guide a decision maker in distinguishing between monetary values (e.g. the costs of water purchase and delivery) and non-monetary values (e.g. maintaining ecosystem integrity). They warn against trying to place

monetary values on all potential benefits provided by water, instead encouraging the articulation of “well posed questions”, e.g. “*I have an option available to reduce water withdrawal to help me meet a company target. The net present value for the project to achieve it is negative. If I take into account all the water values (opportunities and threats), is there a stronger case to invest?*”.

Based on their extensive field work across mining operations in different commodities and environmental contexts, Moran et al. (2008) identify four categories of “difficult to value” water values, including environmental; community; health and safety; and compliance and reputation. This framework offers a fruitful starting point for a mine site decision maker seeking to evaluate and build a business case towards water provision for sustainability benefits.

Step 5. *Implementation and Monitoring*

Having made a business decision regarding the amount of water that the site is willing to make available to deliver water benefits, implementation can commence. It is recommended that the stakeholders initially identified in Step 1 remain engaged throughout this process. Clear agreements must be made to ensure that all parties understand the conditions of resource access. For example, if a site commits to reducing its freshwater intake to provide benefits to the local community, it may seek to forge an agreement that some of this water could be revoked during periods of water restrictions (see Stegink, 2003 for a discussion of when water restrictions were enforced by authorities in an Australian context). This would provide an added-benefit to the site by making it more resilient to maintain production in spite of prolonged drought.

The site could also develop a set of indicators to monitor the progress of the water allocation arrangements to ensure that they are delivering the benefits envisaged. Such an approach would provide the site and community with a tangible understanding about the outcomes from their collaboration, and to celebrate sustainability successes. Brereton and Pattenden (2007) outline a participatory approach that was used to develop a set of indicators for monitoring a mine site’s contribution to community sustainability through engaging management personnel and the Community Liaison Committee (CLC). A similar approach could be adopted for defining a set of water benefit indicators. Consistent with the work of Brereton and Pattenden (2007), it may also be fruitful to distinguish between “lead” and “lag” indicators, with the former referring to efforts that the operation is making towards sustainability, and the latter referring to concrete results or measures of effectiveness. In our context, a “lead” indicator might quantify the amount of water that will be allocated for football fields throughout the upcoming year, while a “lag” indicator might measure the number of people who benefited from using this football field. Another potential data-source for impact monitoring is that of community complaint records. For example, Moran and Brereton (2013) explain that some operating mines – such as coal mines in New South Wales – are required (as part of their operating license) to record community complaints about their activities and to explain how they are addressing these complaints. They explain how these data can be used as an indicator for measuring the cumulative impacts of mining operations at a regional scale. These data could likewise offer an easily accessible and low-cost option for monitoring community opinion about a mine site’s water reallocation efforts.

Discussion and Conclusion

Although the private sector is acknowledged as important for IWRM implementation, practical tools and frameworks to facilitate involvement are lacking. In this field note, we have introduced a framework that could guide a mine site manager towards an active decision to reduce freshwater withdrawal and make this “saved” water available for delivering social and environmental benefits at a community level. Such a decision could provide numerous advantages.

Through performing a rigorous analysis of the site water balance using a systems approach (Step 2), the mine site management team would improve understanding of the risks associated with Wetness and Dryness and could quantify and implement appropriate mitigation measures. A sound understanding of the site water balance is crucial for ensuring water supply security and improving resilience to cope with climatic fluctuations. The decision to make water available for other users may also serve an added benefit of reducing risk exposure. For example, by bringing less water to site for storage, Wetness Risk (series (c) in Figure 2) could be reduced because dam levels would approach their maximum less frequently.

We do however acknowledge that a site's decision to make water available for community benefits could raise a new risk during periods of drought. In the description of Step 5, we suggested that a site could avoid Dryness Risk by forging an agreement with the community to revoke some of its previous water allocation during periods of water restrictions. However in practice, a site may face community opposition if it sought to 'take back' water, regardless of whether formal agreements are in place. We propose two solutions to this dilemma. First, the site must maintain open and transparent dialogue with the community regarding the value of water in a regional context. The mine should demonstrate its operational efforts to drive water stewardship, and communicate the importance of water for sustaining production at the mine. Likewise, staff at the mine site must recognise the value of water at a community level, and eliminate any risk of impeding on human rights. Through this process of mutual exchange, the mine can strive to earn not only a formal, but also a social (Prno and Slocombe, 2012), license to operate. The second solution is for the mine site staff to maintain a sound understanding about their site water balance so that potential Dryness Risk can be detected as early as possible, and solutions to mitigate this risk can be developed well in advance.

The two-way stakeholder engagement process (Steps 3 and 5) would improve awareness among employees and the local community about the value of water for meeting social, environmental and economic (in terms of mine production) needs. For employees, improved appreciation about the importance of water may improve commitments towards targets to reduce water use. Community members would likewise gain an understanding of how water is used throughout the mining process and how this in turn delivers economic values for the community. In the current presentation of the framework, we have proposed that the stakeholder engagement process (Step 3 and 5) should be performed separately from the business decision (Step 4). From the perspective of minimising Dryness and Wetness risk within operations, this appears the most sensible. However to foster a transparent and inclusive decision making process, it may prove more constructive to conduct Steps 3-5 through a collaborative process with the community. For a site wishing to implement such a framework in practice, we therefore suggest that the engagement process be carefully planned according to the contextual environment of the site and following advice from a community relations expert. The current framework focuses on informing decisions about the management of water quantity, however future research could extend the framework to incorporate water *quality* considerations as well. For example, the systems modelling approach described in Step 2 (*Quantify Water Availability*) could be extended to evaluate operational risks with respect to quality constraints. This would be especially important for mining processes wherein salinity changes due to increased water reuse can influence operational performance, e.g. coal flotation (Liu et al., 2011). Additionally, Step 3 (*Identify Potential Benefits*) could be extended to identify water requirements beyond the mining lease with respect to both quantity *and* quality, such that water can be allocated to fit-for-purpose uses.

Another future direction for this research is to consider how such a framework might be expanded to inform decision making by multiple mine sites operating within the same region. Currently, the framework focuses on how a decision making process could take place by a single mining site in collaboration with the community. However, many mining regions are occupied by multiple

operations, wherein cumulative impacts must be considered (Franks et al., 2013; Sonter et al., 2013). In such contexts, mine site managers might find that they can make a greater contribution to IWRM through collaborating with other operations within their regional context.

From a practical perspective, we conclude that a “water benefits” approach offers a novel basis for establishing regional targets. Many companies tend to consider water using an “efficiency” (Côte et al., 2010a) approach, with targets primarily being set on the basis of reducing water use relative to previous performance. From our experiences in engaging with employees on mining sites, such generalised targets are not always perceived as relevant or desirable at localised scales. Encouraging sites to set their own targets based on the perception of water values by the local community may inspire more meaningful sustainability indicators and consequently greater commitment at a site-level.

From an academic perspective, we hope that this field note prompts scholarly discussion about the potential role of mining companies in IWRM and water governance more broadly. The traditional role of the mining sector in questions pertaining to water allocation has been via negotiation with governments to secure access for operations. However mines are increasingly operating in regions wherein their access to water could impede on human rights (Collins and Woodley, 2013; Kemp et al., 2010). Some companies also operate in contexts with weak institutional capacity, such that they may inadvertently find themselves responsible for the provision of public goods – such as water – which were traditionally considered to be roles of nation states (e.g. see the discussion by Cecilia Perla in Rasche et al., 2008). Especially in such contexts – but also in those with sound regulatory frameworks – there are compelling reasons for companies to proactively engage with communities about water values and benefits and to thereby play a more active role in contributing towards IWRM aspirations.

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Reference List

- Abdalla, K.M.E., 2008. Institutional and legal arrangements in the Nile river basin: suggestions to improve the current situation toward adaptive integrated water resources management. *Water Sci. Technol.* 58, 2031-2040.
- Abdullaev, I., Kazbekov, J., Jumaboev, K., Manthritilake, H., 2009. Adoption of integrated water resources management principles and its impacts: lessons from Ferghana Valley. *Water Int.* 34, 230-241.
- Amezaga, J.M., Rotting, T.S., Younger, P.L., Nairn, R.W., Noles, A.J., Oyarzun, R., Quintanilla, J., 2011. A Rich Vein? Mining and the Pursuit of Sustainability. *Environ. Sci. Technol.* 45, 21-26.
- Barrett, D.J., 2009. Thinking outside the lease - Towards a strategic view of regional water management by the mining industry, *Water in Mining 2009*. AusIMM, Perth, Australia, pp. 145-153.
- Biswas, A.K., 2008. Current directions: integrated water resources management - a second look. *Water Int.* 33, 274-278.
- Brereton, D., Beach, R., Cliff, D., 2003. Employee turnover as a sustainability issue, Mineral Council of Australia's 2003 Sustainable Development Conference, Brisbane.
- Brereton, D., Pattenden, C., 2007. Measuring What Matters: Monitoring the contribution of a new mining project to community sustainability, 3rd International Conference on Sustainable Development Indicators in the Minerals Industry, Milos Island, Greece.
- Collins, N., Woodley, A., 2013. Social water assessment protocol: a step towards connecting mining, water and human rights. *Impact Assessment and Project Appraisal* 31, 158-167.
- Corder, G., Moran, C., 2006. The importance of water in the Gladstone Industrial Area, *Water in Mining*, Carlton, Australia, pp. 47-55.
- Côte, C., Moran, C., Hedemann, C., 2007. Evaluating the costs and benefits of salt management strategies at mine sites using a systems model. *Mine Water and the Environment* 26, 229-236.
- Côte, C., Moran, C.J., Acosta, O.J., 2010a. Progressing towards sustainability: From water efficiency to water effectiveness at the Collahuasi mine, in: Wiertz, J. (Ed.), *Water in Mining - 2nd International Congress on Water Management in the Mining Industry (WIM 2010)*. Gecamin, Santiago, Chile.
- Côte, C.M., Moran, C.J., Cummings, J., Ringwood, K., 2009. Developing a water accounting framework for the Australian minerals industry, *Water in Mining*. Australian Institute of Mining and Metallurgy, Perth, Western Australia, pp. 191-203.
- Côte, C.M., Moran, C.J., Hedemann, C.J., Koch, C., 2010b. Systems modelling for effective mine water management. *Environmental Modelling & Software* 25, 1664-1671.
- Department for Victorian Communities, 2013. Sustainable water practices for sport and recreation, Available at: http://www.dpcd.vic.gov.au/data/assets/pdf_file/0019/39214/Sustainable_Facilities.pdf, Accessed on: 8/10/2013.

Department of Environment and Resource Management, 2012. SILO climate data. Queensland Government, Available at: <http://www.longpaddock.qld.gov.au/silo/>, Accessed on: 9/7/2012.

Department of Human Services, 2008. Pool operators' handbook, Available at: http://www.ballarat.vic.gov.au/media/1332477/hs826_pool_operators_web.pdf, Accessed on: 7/10/2013.

Department of Sport and Recreation, 2013. Dimensions for Rugby League. Government of Sport and Recreation, Available at: <http://www.dsr.wa.gov.au/rugbyleaguedimensions>, Accessed on: 8/10/2013.

Devine, J., 2011. High costs of floods confirmed. Queensland Resources Council, Brisbane, Available at: https://www.qrc.org.au/01_cms/details.asp?ID=2835, Accessed on: 13/04/2012.

Franks, D.M., Brereton, D., Moran, C.J., 2013. The cumulative dimensions of impact in resource regions. *Resour. Policy* 38, 640-647.

Gosling, S., 2010. Developing water balance models as an operational tool for sustainable mine water management, *Water in Mining, Chile*.

Gunson, A.J., Klein, B., Veiga, M., Dunbar, S., 2012. Reducing mine water requirements. *J. Clean Prod.* 21, 71-82.

GWP-TAC, 2000. Integrated Water Resources Management, TAC Background Papers No. 4. Global Water Partnership, Stockholm, Sweden, Available at: http://www.gwp.org/Global/GWP-CACENA_Files/en/pdf/tec04.pdf, Accessed on: 08/10/2013.

Halaburka, B.J., Lawrence, J.E., Bischel, H.N., Hsiao, J., Plumlee, M.H., Resh, V.H., Luthy, R.G., 2013. Economic and Ecological Costs and Benefits of Streamflow Augmentation Using Recycled Water in a California Coastal Stream. *Environ. Sci. Technol.* 47, 10735-10743.

Handrek, K., Black, N., 2002. *Growing media - for ornamental plants and turf*, 3rd ed. University of New South Wales, Sydney.

Hering, J.G., Ingold, K.M., 2012. Water Resources Management: What Should Be Integrated? *Science* 336, 1234-1235.

ICMM, 2006. Good practice guidance for mining and biodiversity. International Council on Mining and Metals, London, Available at: <http://www.icmm.com/page/1182>, Accessed on: 8/10/2013.

ICMM, 2012. Water management in mining: a selection of case studies, London, United Kingdom, Available at: <http://www.icmm.com/www.icmm.com/water-case-studies>, Accessed on: 14/09/2013.

ICMM, 2013. 10 principles, Our work, Sustainable Development Framework. International Council on Mining and Metals, Available at: <http://www.icmm.com/our-work/sustainable-development-framework/10-principles>, Accessed on: 14/09/2013.

Jeffrey, P.J., Gearey, M., 2006. Integrated water resources management: lost on the road from ambition to realisation? *Water Sci. Technol.* 53, 1-8.

Kemp, D., Bond, C.J., Franks, D.M., Côte, C., 2010. Mining, water and human rights: making the connection. *J. Clean Prod.* 18, 1553-1562.

Kunz, N.C., Moran, C.J., Kastle, T., 2013. Conceptualising “coupling” for sustainability implementation in the industrial sector: a review of the field and projection of future research opportunities. *J. Clean Prod.* 53, 69-80.

Kuosmanen, T., Kortelainen, M., 2007. Valuing environmental factors in cost–benefit analysis using data envelopment analysis. *Ecol. Econ.* 62, 56-65.

Lienert, J., Schnetzer, F., Ingold, K., 2013. Stakeholder analysis combined with social network analysis provides fine-grained insights into water infrastructure planning processes. *Journal of Environmental Management* 125, 134-148.

Liu, J., Zehnder, A.J.B., Yang, H., 2009. Global consumptive water use for crop production: The importance of green water and virtual water. *Water Resour. Res.* 45, W05428.

Liu, W., Moran, C.J., Vink, S., 2011. Quantitative Risk-Based Approach for Improving Water Quality Management in Mining. *Environ. Sci. Technol.* 45, 7459-7464.

Minerals Council of Australia, 2005. Enduring value - The Australian minerals industry framework for sustainable development, Kingston, ACT, Available at: http://www.minerals.org.au/file_upload/files/resources/enduring_value/EV_GuidanceForImplementation_July2005.pdf, Accessed on: 8/10/2013.

Moran, C., Evans, R., Silvester, N., Ringwood, K., 2008. Characterising the values of water in minerals operations, in: Wiertz, J. (Ed.), *Water in Mining 2008*. GECAMIN, Santiago, Chile, pp. 3-18.

Moran, C., Syme, G.J., Hatfield-Dodds, S., Porter, N., Kington, E.A., Bates, L., 2004. On defining and measuring the benefits from water, 2nd IWA Leading-Edge Conference on Sustainability: Sustainability in Water Limited Environments. *Water Intelligence Online*, IWA Publishing 2006, Sydney, Australia.

Moran, C.J., 2006. Linking the values of water to sustainability, *Water in Mining 2006*. AusIMM, Brisbane, Australia, pp. 113-121.

Moran, C.J., Brereton, D., 2013. The use of aggregate complaints data as an indicator of cumulative social impacts of mining: A case study from the Hunter valley, NSW, Australia. *Resour. Policy* 38, 704-712.

Prno, J., Slocumbe, D.S., 2012. Exploring the origins of 'social license to operate' in the mining sector: Perspectives from governance and sustainability theories. *Resour. Policy* 37, 346-357.

Rasche, A., Baur, D., Van Huijstee, M., Ladek, S., Naidu, J., Perla, C., Schouten, E., Valente, M., Zhang, M., 2008. Corporations as political actors - A report on the first Swiss master class in corporate social responsibility. *J. Bus. Ethics* 80, 151-173.

Ringwood, K., 2006. The value of water to Rio Tinto, *Water in Mining*. AusIMM, Brisbane, Australia, pp. 131-136.

Rio Tinto, 2008. Rio Tinto and biodiversity: Achieving results on the ground, England, Available at: <http://www.riotinto.com/documents/ReportsPublications/RTBiodiversitystrategyfinal.pdf>, Accessed on: 8/10/2013.

Rio Tinto, 2013. Kestrel Mine - Site report, Rio Tinto Coal Australia, Available at: http://www.riotintocoalaustralia.com.au/ouoperations/321_kestrel_mine_458.asp, Accessed on: 7/10/2013.

SAI, 2007. Sustainable Agriculture Initiative Platform - Annual Report 2007, Brussels, Belgium, Available at: http://www.saiplatform.org/uploads/Library/SAI_RA_v12_LowResolution.pdf, Accessed on: 8/10/2013.

Sonter, L.J., Moran, C.J., Barrett, D.J., 2013. Modeling the impact of revegetation on regional water quality: A collective approach to manage the cumulative impacts of mining in the Bowen Basin, Australia. *Resour. Policy* 38, 670-677.

Stegink, H.D.J., Lane, J., Barker, D.J. and Pei, B., 2003. Water usage reductions at Queensland Alumina, *Water in Mining 2003*, Brisbane, pp. 293-299.

Syme, G.J., Nancarrow, B.E., 2008. Justice and the Allocation of Benefits from Water. *Social Alternatives* 27, 21-25.

Syme, G.J., Porter, N.B., Goeft, U., Kington, E.A., 2008. Integrating social well being into assessments of water policy: meeting the challenge for decision makers. *Water Policy* 10, 323-343.

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Appendix: Assumptions accompanying Table 1

Water required for irrigation (parks, gardens, football field, golf course)

Equation for water use:

The amount of water required to replace evapotranspiration is given by (Handreck and Black, 2002):

- $Water\ Use\ (mm/year) = Pan\ Evaporation\ (mm/year) \times Crop\ Factor$

Assumptions:

- Pan evaporation = 2133mm/year [average yearly evaporation for the town of Emerald based on SILO data between 1889-2005 (Department of Environment and Resource Management, 2012)]
- Crop factor = 0.625. Handreck and Black (2002) provide a crop factor between 0.55-0.7 for warm season, vigorous, lush grass. We take the average of these values.

Water use required for irrigation:

Using the above assumptions, the annual water requirements for turf grass were thus calculated at 1.33m/year for each unit of irrigation area.

Irrigation areas:

- Public playground area was estimated.
- Garden area was estimated from Google Earth.
- Football field dimensions are 100m × 68m (Department of Sport and Recreation, 2013)
- The Middlemount golf course is approximately 8-9 hectares (determined through personal communication with the greenkeeper). We assume an average area of 85,000m².

Water required for a swimming pool

Swimming pool requirements were calculated based on the water needed to cover evaporation, backwash and an annual complete empty of the pool.

Assumptions:

- Pool dimensions are 50m × 25m × 2m (Department of Human Services, 2008)
- Backwash requirement = 52kL/week = 2.7 ML/year (Department for Victorian Communities, 2013)
- Pan evaporation = 2133mm/year (see above)

Freshwater use by the Kestrel mine

- Rate of freshwater use = 402 litres per tonne of product coal (Rio Tinto, 2013)
- Total saleable production = 2.8 million tonnes (Rio Tinto, 2013)

$$Total\ freshwater\ use\ (in\ 2012) = 402 \frac{L}{tonne} \times 2.8 \times 10^6\ tonne = 125.6ML$$

Highlights:

- Mining sites can contribute towards IWRM
- A “water benefits” perspective offers an implementation pathway
- Practical frameworks are needed to support decision making at a site level
- We provide a foundation for further scholarly/industry debate

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