

Water management capacity building to support rapidly developing mining economies

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Abstract

Many developing countries are experiencing rapid expansion in mining with associated water impacts. In most cases mining expansion is outpacing the building of national capacity to ensure that sustainable water management practices are implemented. Since 2011, Australia's International Mining for Development Centre (IM4DC) has funded capacity building in such countries including a program of water projects. Five projects in particular (principally covering experiences from Peru, Colombia, Ghana, Zambia, Indonesia, Philippines and Mongolia) have provided insight into water capacity building priorities and opportunities. This paper reviews the challenges faced by water stakeholders, and proposes the associated capacity needs. The paper uses the evidence derived from the IM4DC projects to develop a set of specific capacity-building recommendations. Recommendations include: the incorporation of mine water management in engineering and environmental undergraduate courses; secondments of staff to suitable partner organisations; training to allow site staff to effectively monitor water including community impacts; leadership training to support a water stewardship culture; training of officials to support implementation of catchment management approaches; and the empowerment of communities to recognise and negotiate solutions to mine-related risks. New initiatives to fund the transfer of multi-disciplinary knowledge from nations with well-developed water management practices are called for.

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1. Introduction

This paper aims to identify priorities for water management capacity building to support rapidly developing mining economies. This aim is motivated by the recognition that extraction of minerals should lead to a permanent positive legacy in terms of social, economic and natural capital ([International Institute for Environment and Development, 2002](#)), and that effective water management is central to this goal.

1.1. Capacity for sustainable mining

The idea that there can be sustainable improvements in local, national and global life quality arising from extracting non-renewables is the essence of the term ‘sustainable mining’ ([Giurco & Cooper, 2012](#)). The sector is faced with the task of increasing production to meet global demands for metals and other minerals; and with much of the more easily accessible and higher quality minerals having already been mined, more land, water and energy will be required just to maintain production levels ([Powell & Bye, 2009](#)). The sector is turning to countries that in the past have not been attractive to foreign investment either due to government policy, political instability or corruption ([O’Neill, 1993](#)). In turn, in many countries, rapid expansion of the large-scale mining industry is, or is set to be, a core part of poverty alleviation and wealth development strategy, increasing the urgency of the sustainability challenge in the nexus between land, water and energy resources.

Part of the solution to the water, land and energy demand problem must lie in improving a nation’s capacity to develop and implement best practices in terms of science and technology, project management, regional planning and effective communication and regulation. Indeed, it is widely recognised that achieving more sustainable production requires a wide range of expertise to serve and complement the mining industry’s core business of extracting minerals ([International Institute for Environment and Development, 2002](#); [ICMM, 2012](#)). This includes the need for capacity in the social, engineering and environmental sciences, covering people from mining companies, governments and other bodies representing the interests of land users and other stakeholders, and universities and other providers of education, training and research services ([Reichardt, 2009](#)). This approach should also consider the potential to integrate with near neighbours and global trends in resource management. It is this need that drove the development of the International Mining for Development Centre (IM4DC) in Australia, and comparable centers internationally aimed at knowledge transfer and capacity building to support sustainable development of the mining industry in developing countries.

Water management is one of several priority areas for capacity building. Many activities during the mine project life cycle involve management of water, summarised in [Table 1](#) (from [DRET, 2008](#)). Water is often required in larger quantities than can be provided sustainably from local sources ([Anglo American, 2013](#)), creating risks associated with water supply and abstraction impacts. The interaction of mines with the hydrological cycle also poses floods, geotechnical and pollution risks, both immediate and as long-term liabilities, from local to catchment scales ([Younger & Wolkersdorfer, 2004](#)). The economic, environmental, social and cultural importance of water to different sets of people in a mining region, and the influence these sets of people can have on the success of a mining venture, create new business and political risks as well as opportunities ([Davis & Franks, 2014](#)). In some areas, most livelihoods depend on local water sources ([Whittington et al., 1990](#)) and communities, and sectors within communities, can be disproportionately impacted by any changes to hydrological regimes or

Table 1. Water management activities associated with the mine life cycle (adapted from DRET, 2008).

1. Exploration and resource development	2. Mining, minerals processing and transport
<ul style="list-style-type: none"> • Water supply to site • Wastewater discharges • Discharge of excess drilling water • Site stormwater management • Groundwater investigations • Design, approval and development of all items under 2 and 3 	<ul style="list-style-type: none"> • Water supply, storage, treatment, re-use and recycling • Water diversions • Wastewater disposal • Excess stormwater and groundwater management • Dust suppression • Spillage management • Washing of vehicles • Catchment management including water resources offsetting and water sharing schemes • Monitoring and reporting
3. Rehabilitation	4. Post-mining
<ul style="list-style-type: none"> • Stream restoration • Contaminated soil and water remediation • Decommissioning of water infrastructure • Mine pit lake modelling • Catchment management planning 	<ul style="list-style-type: none"> • Rehabilitation performance monitoring • Erosion and drainage management • Contaminated soil and water remediation

water quality. This means that mine water managers should not constrain their roles to the immediate concerns of production and safety, but also consider both the offsite and legacy impacts of water abstraction and use. Thus site water management, and sustainable and equitable regional water resources management in mining regions are key elements among priorities for capacity building (Danoucaras *et al.*, 2012).

1.2. Aim, approach and scope of paper

This paper aims to provide direction for investments in education and training programs to support sustainable mining, and the employee, government and community training and education needs. The approach taken is as follows:

- Review of the current water challenges facing the mining industry focussing on rapidly developing mining economies, covering first technical challenges and then socio-economic, environmental and governance challenges.
- Interpretation of these challenges in terms of potential education and training needs.
- Review of the experiences and outcomes of five water projects conducted by Australia's IM4DC during the period 2011–2014.
- Synthesis of these project reviews and our interpretations into a set of recommendations to guide future education and training programs.

The paper gives broad representation to the mining sector, and does not aim to cover all the water management issues that may be important locally, and pays less attention to issues that we consider are generic across all resource and industry sectors rather than having special relevance to mining

regions. The paper includes challenges of small-scale and illegal mining as well as large-scale mining, as the former two types of mining have emerged in some regions as the more significant problem (Tarras-Wahlber *et al.*, 2000, Olivero-Verbel *et al.*, 2004, Cordy *et al.*, 2011). While we aim for wide geographic relevance, the findings here come largely from our experiences working with people from Peru, Colombia, Ghana, Zambia, Indonesia, Philippines and Mongolia. The paper does not attempt to cover foundation education needs, but focuses on needs of final-year undergraduates, post-graduates and professionals who have an undergraduate foundation in environmental science, environmental management or environmental engineering (such as commonly taught, for example, in university civil engineering and environmental science programs). The paper addresses the needs for translating this background to build relevant water management capacity.

First, it is useful to expand on the main water management challenges associated with mining. This will be done here only just sufficiently to contextualise our findings about education and training needs.

2. Mine water management – introduction to challenges and associated capacity needs

The water problems facing mines may be categorised into those related to managing impacts due to: the consumption of water by mining and supply needs; water surplus in mine sites; hydrological change due to mine projects; and pollution due to mine projects. Each of these is addressed in this section in terms of defining the issue and commenting on implications for technical education and training needs. The subsequent section will address the capacity needs for managing these water issues from local to regional scales, including cumulative impacts assessment, community perceptions and relations, and regulation and governance.

2.1. Technical challenges

For the purpose of our categorisation, water used in and then discharged from a mine site is not considered to be water consumed. Rather, the consumption of water is primarily through evaporation losses (DRET, 2008) and water entrained long-term into tailings (tailings being the main waste product of metal ore processing). Consumption is most relevant in water-scarce areas, where the consumption rate must be met by drawing on valuable water supplies from outside the mine site area. Designing these supplies requires water resources engineering expertise. Controlling water evaporation mainly involves reducing storage of water, in particular open water surfaces, which requires good understanding of storage needs, and good design and operation of storage and tailings facilities; and can involve innovative evaporation control. Tailings hydraulic properties and the various technologies used to separate water from the tailings, both in the processing plant and at the tailings pond, will affect entrainment; optimising this requires understanding of solid–liquid separation techniques and rheology (Jones & Boger, 2012). Closed mines with re-established soils and vegetation are likely to have evapotranspiration (evaporation plus plant transpiration) losses that are higher than those from an operating mine (Brom *et al.*, 2012); so estimating and managing the consumption of water by closed mine sites requires soil and eco-hydrology expertise. Increasingly, remote sensing expertise is considered important to estimate the spatial variability of climate, soil moisture and vegetation in evapotranspiration calculations.

Water surplus occurs where groundwater inflows, surface water runoff into the mine site and precipitation into the mine site exceed the water consumption over a defined time period. In most cases, the

water surplus over short periods is stored and used in the mine site to balance water consumption over longer periods. Where the mine pit extends well below the water table, there is likely to be continual water surplus, which requires water to be pumped out of the mine site to a place where it does not return to the mine site in appreciable volumes. The need for pumping creates cost as well as potential adverse effects on hydrological regimes (see below) but also opportunity for beneficial re-use of pit water in water-scarce areas (water quality notwithstanding) (McCullough & Lund, 2006). To manage these risks and opportunities, good understanding of groundwater regimes, water infrastructure, potential water uses, environmental impacts, and values to society is required. Other risks from surplus water arise when pumping and/or storage capacity is exceeded and mine pits fill with water causing disruption to production and increased geotechnical hazards. In extreme cases, pits may overflow or tailings dams fail creating safety risks. Managing these types of risks requires an understanding of hydro-climate variability, climate change and geotechnical engineering.

Hydrological regime change relates to the impacts that mines have on the space and time distribution of water in the catchment (Ferrari *et al.*, 2009). This can have a variety of causes, but the principal cause is likely to be the drawdown of the water table/aquifer pressures due to inflows into mine pits. Another important issue is the abstraction of river flows and storage of surface runoff on the site, reducing river flows and smoothing out natural time variability of flows. Hydrological and hydrogeological expertise is needed to predict and manage impacts; and technical expertise in operational water efficiency and water treatment to maximise water re-use and recycling. In other cases, particularly arid regions, significant volumes of groundwater may need to be disposed of from open cut or underground operations, at times or in regions where limited or no surface water flows would occur naturally, creating altered hydrological regimes and ecosystems. Again, hydrological and hydrogeological expertise is needed to predict and manage impacts, along with an understanding of ecology and ecosystem performance in areas of disposal or abstraction. Climate change, natural variability and the influence of other land and water users complicate the interpretation of observed changes in hydrological regimes. The relevance of hydrological regimes (as opposed to time and space-averaged water balances) on ecosystem service, ecosystem resilience and cultural values of water needs to be understood as part of impacts assessment (Carpenter *et al.*, 2009).

Pollution is the last of our four categories of mine water impacts. As in almost all other industrial processes, chemicals are used in minerals processing or extraction and residues of these chemicals are present in wastewater and solid wastes (for example tailings). Localised knowledge and educational capacity is needed to support optimal use of chemicals, appropriate treatment technology, including for small-scale mining (Cordy *et al.*, 2011), and monitoring of performance and residuals in discharges. As in all landscape modification projects, management of erosion and subsequent geomorphological change and pollution is a major challenge requiring understanding of interactions between hydrology, geochemistry and geomorphology (Sarma & Batik, 2012). Geochemistry capacity is particularly relevant for mining, which usually involves the exposure, blasting and grinding of rock, separation of minerals and on-site disposal of waste rock fragments. The exposure of large surface areas of rock to water and the atmosphere can cause acidification (known as acid rock drainage or acid mine drainage) and associated mineral dissolution and toxicity in runoff, infiltration and stored water. The conditions in which this occurs and the corresponding solutions are dependent on hydrogeology and geochemistry (Riley *et al.*, 1984). More so than in other industries, hydrogeological and geochemical expertise is essential for effective pollution and risk management. Additional training and education in post operational mine and void management options, expertise and rehabilitation strategies are also required.

It is also necessary to introduce the technical challenges associated with cumulative impacts assessment. Cumulative impacts assessment (as opposed to impacts of individual projects and individual stages in a mine region's development) is a critical part of evaluating risks and opportunities associated with mining (Lucas *et al.*, 2009). Regulators in developing countries are faced with economically important decisions about permitting mine developments, often with minimal capacity to predict cumulative impacts. Aspects of cumulative impacts assessment that drive technical capacity needs are the greater time and space scales, greater number of factors contributing to changes in water resources, the resilience and capacity of the receiving environment, and the special expertise needed to manage large data sets, for example in GIS systems (Deitch *et al.*, 2013). The importance of observations to develop cumulative impacts models, yet the expense of making direct observations of subsurface properties in the whole catchment (that may occur across multiple operations or leases), means that expertise is also required in remote sensing and modelling techniques such as geophysical methods, geostatistical modelling and other data regionalisation and extension techniques (Oldershaw *et al.*, 2012). The nature of the monitoring and assessment capabilities dictates a multidisciplinary approach that requires an advanced level technical capacity and ability to work effectively across the sub-disciplines, which is also needed for cumulative impacts, is found in only a few organisations internationally. Furthermore, cumulative impacts assessment calls for experience and skills prior to mining, during extraction and beyond mine-life management; and in engaging stakeholder groups, which will be addressed in the next section.

2.2. Socio-economic and governance challenges

Improved contribution to catchment scale management of water can be partly achieved by embedding the mining industry into integrated water resources management (IWRM) frameworks, whereby different land and water users work together to identify and achieve catchment scale goals (Younger & Wolkersdorfer, 2004). Generically, IWRM may be considered to require: (1) development of understanding of the physical water system and baseline conditions; (2) identification of water users, water values and relevant metrics of impact; (3) development of scenarios of the future; (4) modelling to evaluate impacts; (5) an inclusive land and water management decision-making process; (6) a regulatory framework which allows information (and its periodic updating) to be incorporated in regulations and for these regulations to be enforced; and (7) appropriate policy and transboundary instruments to act as enablers for the state, industry and community (Orlove & Caton, 2010; Carmona *et al.*, 2013). The steps are periodically reviewed to allow for changing conditions and new information. IWRM is potentially relevant for any catchment and implementations in one form or another are common. However, in rapidly developing nations, it is likely that capacity for IWRM has not kept up with the emerging risks and opportunities (Anderson *et al.*, 2009). Especially in these cases, mining companies may need to drive IWRM beyond what is effectively legislated to satisfy their own and investors' performance standards and safeguard social license.

Two potential barriers to achieving effective IWRM in mining regions deserve more detailed attention here. (1) Regarding the goal of an inclusive decision-making process – understanding community values and how to manage community expectations and relations. This addresses the common problems of competition for water and mistrust of companies by communities (Bebbington & Williams, 2008). (2) Regarding regulatory frameworks – the need for effective reporting, monitoring, regulation and governance. This addresses the dual pressure on governments to permit rapid development of mining and to

protect the broader and longer-term value of water. This may have relevance across borders for large catchments or river basins.

Understanding the values attached to water allows metrics of performance to be determined and managed. The short-term and direct economic value of water use can be relatively well quantified (Damigos, 2006; Evans *et al.*, 2006); for example the water consumption on a mine site per tonne of product produced is an easy-to-define metric (although of course there will still be considerable uncertainty and variability). On the other hand, the less direct links between economic benefits and hydrological regime metrics, for example through the regulating ecosystem services provided by rivers, requires a greater range of expertise (Nyoka & Brent, 2007; Bai *et al.*, 2011; Rosa & Sánchez, 2013). Similarly, the objective valuations of human health, cultural and spiritual attributes of water are more challenging, requiring capacity also in the social science domain, including capacity to uncover, interpret and appropriately report and use community knowledge, cultural history, opinions and feelings.

Building good relations with communities is central to understanding their water values and negotiating how mine water management can protect and augment these values (Kemp *et al.*, 2010; Collins & Woodley, 2013). Irrespective of the technical merits of mine water management plans and regional/national socio-economic benefits of the mine project, poor relations with local communities can be a deciding factor in the project's success, can influence the company's global reputation and increase operational costs (Franks *et al.*, 2014). The need to build these relations – to build understanding and trust about what the risks and opportunities are, how they are assessed, and how solutions are implemented and evaluated – is perhaps the greatest capacity building challenge because it needs teams who can effectively work across the social, natural and engineering science aspects of the problem. Few education and training institutions can develop individuals and teams who can provide that multidisciplinary capacity.

In the last two decades there has been a discernable shift towards greater stakeholder involvement and participation in policy-making and a trend towards an emphasis on good governance (Acquah, 1994; Hodges, 1995; Heere, 2004; Rieu-Clarke *et al.*, 2010). Good governance is seen as a mechanism for citizens and groups to articulate their interests, mediate their differences and exercise their legal rights and obligations (Tiainen *et al.*, 2014). Understanding the role of law and administration, legal and operational frameworks is also required to provide a legitimate and predicable environment in which to support sustainable water management (Gooch *et al.*, 2010). Thus an improved stakeholder and community involvement necessitates greater knowledge of policy, process and thereby governance surrounding water management. Further, for governance to be effective, the local level of government working with mining companies has a large role in addressing social impacts (Everingham, 2007). In this context, the governance of small-scale mining can be very different to large-scale mining. For example, chiefs and families may own the land that is mined, and so the small-scale miners negotiate with them rather than with the local/national government. There can sometimes be a security threat if the government tries to interfere in this localised operation.

Arguably the priority needs for small-scale and illegal mining relate to managing the economic drivers – economic and educational frameworks to give incentive and support to use cleaner technology; and design of good policy (Mutemeri & Petersen, 2002). It is difficult to argue that merely formalising the sector will ensure better outcomes. An illustration is in Ghana, which has regulated artisanal scale mining. Maconachie & Hilson (2011) indicated that Ghanaian policy favoured large-scale mining. Their argument was that the Ghanaian Government leased the most suitable land for prospecting to large-scale companies for their exclusive use. Thus if artisanal scale miners want to increase their likelihood of

finding gold, they will illegally work on the lease of a large-scale mining company. Other factors that increase the prevalence of illegal mining over licensed small-scale mining are that the licensing procedure is complex and bureaucratic, and that for some it has been a traditional livelihood over generations. This illustrates the need for multi-disciplinary capacity to develop water management solutions within complex social and political contexts of artisanal mining activity.

3. Identifying education and training needs – insights from the IM4DC water program

The IM4DC is a centre funded by the Australian Government between 2011 and 2015 to deliver capacity building to support sustainable growth of mining in developing countries. IM4DC activities have extensively covered social, economic, governance and environmental dimensions of the challenge. This has included five training and research projects that collectively have developed new insight into water management education and training needs. The projects have targeted countries that are either experiencing rapid development of the mining sector or have an option to do so. Activity reports for all of these are published on the IM4DC website (Danoucaras *et al.*, 2012, 2014; McIntyre, 2014a, b; McIntyre *et al.*, 2014), which cover the full range of outcomes. In this paper, we focus on summarising the insight into education and training needs identified, primarily from participants in the 3-week knowledge exchange event in 2013, which formally collected data on training needs perceptions.

3.1. Water in mining knowledge exchange event

In November 2013, 16 invitees participated in a 3-week IM4DC knowledge-exchange event held in Brisbane (McIntyre, 2014b). The participants represented Peru, Mongolia, Indonesia, Philippines, Ghana and Zambia. There were eight representatives of government, nine from universities and other training/research organisations; and three representing mining companies (four participants had dual representations). As part of this event, the 16 participants presented the water management challenges being faced in their own countries; wrote and discussed commentaries on how aspects of good practice might be transferred to/from their nations; and responded to verbal and written surveys about priority training needs in their countries.

Most of the surveys were one to one, however, due to the need for some translation, some participants were interviewed in small groups (no more than three). Two participants submitted a written survey rather than being verbally interviewed. While the interview was based around a set of questions, context-specific discussions were also recorded and fed into results. The surveys were based around a set of questions, developed in consultation with the co-authors as well as experts in training course design at The University of Queensland's Centre for Innovation in Professional Learning. Much of the valuable information obtained relates to the priority training needs, and the rest of this section describes these results.

The participants were first asked to prioritise training needs guided by (but not restricted to) this list of topic areas:

- Mining's impact on livelihoods.
- Mining's impact on health and sanitation.

- Artisanal scale mining.
- Mining impact on water security.
- Community/company relationship/trust.
- Environmental impacts of low quality water.
- Impacts of climate change.
- Technical improvements to mine water management.
- Biodiversity impacts.

Results are summarised in Figure 1. The participants were also asked to explain the reason for their answers.

Artisanal scale mining was identified as the priority issue by seven participants. The primary explanations for this were the urgent need for pollution control both during and after mining; lack of understanding of miners and communities about the pollution risks and solutions; governance challenges, including the potential conflict with local and traditional land governance if central government attempts to intervene; and cross-boundary governance complications associated with migrant workers. Priority training needs were considered to be training on how to use clean processing technology; training on how to rehabilitate closed small-scale mines; and on governance of small-scale mining including developing legislation and frameworks for co-existence with large-scale mining.

The issue of community and company relationships was seen as the top issue by five participants. It was felt there was a need for communities to better understand technical water management issues, as well as a need for companies to acknowledge and use local knowledge, and to understand and respect

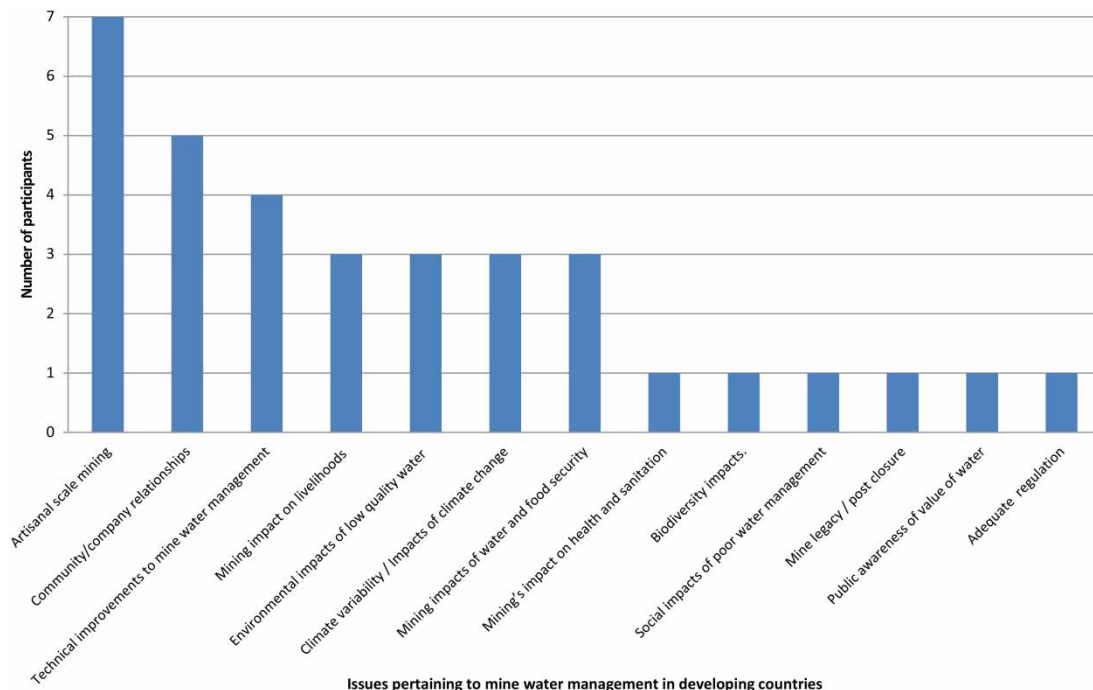


Fig. 1. Perceptions of issues driving training needs – results of a survey of 16 course participants.

local values. The need to work towards shared values was repeatedly noted. The group noted that communities are increasingly aware of the environmental risks; and this is not usually matched by increasing awareness of good practice technical solutions. Training priorities include developing awareness of the social water context that mine sites operate in and to incorporate this awareness into technical solutions; and training is needed on the environmental/social/economic benefits of leading practice rather than compliant water management. Training is needed towards achieving better transparency in water management by mining companies; and teaching of technical issues to communities.

The need for technical improvements to mine water management was identified as a top issue by four participants. Hydrological and hydrogeological modelling training was considered to follow poor practice in many cases, and training is needed to develop cumulative impact models that are suitable for local conditions rather than use of over-generic models. It was noted that not enough mines have their own laboratories capable of basic chemistry analysis, which makes it difficult to monitor water quality; and greater knowledge is needed about use of low-cost water quality analysis techniques. Greater knowledge is needed in general about best technical practices to allow mine water managers to assess their performance and introduce new solutions.

Mining's impact on water and food security was identified as a top issue by three participants, as was the connected issue of climate variability and change. The dependence of local livelihoods on irrigated agriculture was one reason; another was the limited understanding of some mine water managers about their water use and the needs of other users in the catchment, which is exacerbated when multiple mines are operating in the single catchment. The vulnerability of both agriculture and mining to droughts and floods was seen as pointing to the potential importance of climate change adaptation capacity. Training needs to address these include: use of standard water accounting methods and benchmarking to identify opportunities for improving water use efficiency; towards understanding the hydrological properties of catchments and hence the water supply constraints; approaches to adaptive water management in face of increasing climate variability; and how to include other water users in an integrated management strategy.

The capacity needed to address the environmental impacts of low quality water was identified as a top issue by three participants. As well as the need to improve understanding and management of the quality of discharged water (already covered above), it was felt that the negative impacts of pollution, including biodiversity impacts, may often be disproportionate to the benefits of mining. This was often not recognised especially due to delays between impacts and when the impacts are realised and the cost of rehabilitation that may be required. Training on this was called for.

Mining's impact on livelihoods was identified as a top issue by three participants, with reasons and training needs echoing those already given above.

The participants were then asked to give their views about the sufficiency of *current training programs for meeting the water management needs of different stakeholders*. The responses generally indicated the low level of activity in provision of training, with exceptions. The participants from Ghana responded that training of small-scale miners is being promoted, for example by the World Bank and European Union, but only reaches licensed miners rather than also illegal miners. In addition, since a lot of small-scale miners are nomadic, it can be difficult to train them and evaluate the success of the training. Putting aside time to undertake non-obligatory training is problematic for all types of stakeholder. Courses are often short and lacking substance, especially on closed mine and tailings water management. Training for government and mining companies does not sufficiently cover the issue of community values in general, although in some countries there are initiatives to do so. There was a common view that cross-disciplinary training be provided to a range of audiences, with the recognition

that there needs to be specific courses for different types of audience, in particular recognising the needs of communities and localised issues.

The participants were asked to provide further comment on which groups of stakeholders should be targeted as priorities for training. For mining company staff, it was considered important to target mid-level personnel. This is because they have enough responsibility to make decisions, can train people lower than them and will likely be less busy than more senior staff. For water management, the training should especially target environmental managers from mine sites. Training programs should be developed targeting those in control of local land and water governance; as well as officials from each country's national water authority, mining/energy agencies and university staff. The importance of school and further education was noted, so that the next generation has a better scientific baseline.

Overall, participants were aware of several initiatives by governments, non-governmental organisations (NGOs) and universities to provide training programs to a variety of stakeholders, however there was a clear recognition that much more thought and investment is required towards immediate training needs and long-term capacity building.

3.2. Other IM4DC and related activities contributing to new knowledge of water education and training needs

Danoucaras *et al.* (2012) reviewed the scientific literature relevant to priority areas of research and training. The review focussed on papers describing issues in Mozambique, Zambia, Ghana, Peru, Mongolia, Philippines, Papua New Guinea and Indonesia. The main points from the review relate to the illegal mining problem, IWRM, community participation and communication of technical information. The review highlighted the importance of management of illegal and small-scale mining, and the challenge of implementing regulations and opportunity for large-scale mining companies to provide good practice training to small-scale miners. It was found that community mistrust arises due to difficulty of communication of technical material and accessibility of unbiased scientific results, hence calling for capacity in science communication. The reviewed papers highlighted the potential benefits of companies engaging with communities through participatory monitoring of impacts; and the drive towards IWRM principles.

Danoucaras *et al.* (2014) followed up some of these findings by a case study in Ghana, in a region dominated by small-scale mining as well as one large gold mine run by a foreign company, with the main objectives of identifying opportunities for participatory monitoring and to test a protocol for assessing social values attached to water. In terms of education and training needs, it was found that community had little to no understanding of the term 'water quality'. Instead, the term 'water safety' was used by the researchers to convey whether or not the water was fit for purpose. The relationship between the mining company and the community was strained despite many formal structures such as regular meetings for facilitating communication. It indicated that the mining company could practice more sophisticated community relations and would benefit from training in this area.

In April 2014, a 1-week IM4DC Action Research workshop was held in Lima, with the objectives of identifying opportunities for better modelling and management of freshwater ecosystem services in mining regions of the tropical Andean nations, which included discussions of research and training needs. The 15 participants were representatives from a:

- NGO specialising in catchment management and sustainable livelihoods;
- large mining company;

- government scientific organisation;
- water management consultant; and
- catchment management initiative.

All these were Peru based; and additionally Colombian, Peruvian, Australian and UK universities with water management expertise were represented, and expertise in water governance from Australia.

During the IM4DC Action Research workshop, the participants collectively designed and populated a matrix (McIntyre et al., 2014) describing training needs related to catchment water management in mining regions. An outcome was the lack of advanced technical skills to undertake assessments of hydrological and pollution risks, especially long-term risks. This applies to all stakeholder groups. Technical skills developed in undergraduate courses should be put into a mining context in relevant post-graduate courses; and water management should have a stronger role in mining engineering courses. Post-graduate training, in particular at PhD level, is needed to provide high-level expertise especially to support government research institutions and universities, including training in communicating science clearly. The discussions also placed emphasis on the community relations training needs of mine company staff, regulators and local authorities. Other prominent outcomes of the discussions were: the need for better understanding of the values of water and water rights; the need for training on monitoring reporting and auditing of water management performance; and the need for greater understanding of the concepts of uncertainty and risk. The same project also involved visits to universities in Lima, where staff noted the lack of PhD-qualified staff, and thus lack of specialists for providing training and leading research projects.

The value of specialist training in mine water management to final year undergraduate engineering students was explored in July 2014, when IM4DC co-sponsored a 2-week summer school at Los Andes University in Colombia (McIntyre, 2014a). This training course was provided in the expectation that some of the participants will ultimately play important roles in the development of Colombia's large-scale mining sector. There was considered to be value in a 2-week intense introduction to mine water management, which complements and uses the technical knowledge and skills gained in the preceding 4 years of their undergraduate courses. The summer school provided lectures covering the major technical and social challenges, and a 4-day case study project to develop components of a mine water management plan. The 33 participants rated the relevance of the course to their future careers as 4.4/5 on average. Comments included the value of the training in terms of receiving an objective view of the sustainable mining challenge and water management pathways; the value of the combined technical and social viewpoints; and insights into the small-scale and illegal mining problem.

Although exploratory, we conclude from the experience of the Los Andes summer school there is potentially major benefit in mine water management education and training embedded in the final years of undergraduate or taught post-graduate programs, especially in countries facing the prospect of rapid mining development.

4. Recommendations for education and training

The data and experiences collected during IM4DC-funded water management projects provide valuable evidence to supplement the observations made in Section 2 about education and training needs in countries with rapidly developing mining sectors. Here we synthesise the results and discussions in Sections 2 and 3 into recommendations for each of five groups of people: university students; university,

research organisation and water consultancy staff; mining company staff; policy makers and regulators; and community representatives. The set of recommendations is our subjective synthesis of the range of information presented above and we do not attempt to objectively link recommendations to collected data.

4.1. University students

Water management theory and practice to a large extent are common across different sectors. The same baseline skills and knowledge typically acquired in relevant university degree courses, for example civil engineering, water resources engineering, environmental science and environmental management degree courses. Relevant water resources management courses are increasingly appearing internationally at post-graduate level, including courses aiming to give a valuable cross-disciplinary perspective. However, mining regions pose special management problems – the importance of hydrogeology and geochemistry, the water conflict aspects (local, regional and transboundary), and the opportunities associated with large investments in water infrastructure. The new sources of water that can be made by mining, the landscape changes that happen over the mine life cycle, and the water technology needs of mine site operations warrant consideration. In terms of preparing graduates for a role in sustainable development of mining regions, and providing them insight into the potential importance of their own contribution to mining development, we recommend teaching modules and opportunities for project work focussed on mine water to complement the more generic water science and management modules.

4.2. University, research organisation and water consultancy staff

The potential role of these staff is to provide the water-related education, training, research and consultancy services to support sustainable development of mining. It is difficult to generalise about training needs because of the variety of backgrounds involved, for example some members of this group have considerable experience in countries with well-developed mining industries. However, it is clear that in-country institutions (in developing countries) often lack people who have had substantial exposure to good practice in mine water management. Like the student group, the people with good knowledge of mining tend to come from mining engineering and industry training backgrounds. Institutions also often lack people with high-level expertise, such as that developed in PhD programs, in critical areas such as hydrogeochemistry of mines and tailings dam hydrology. This calls for investment in exchanges where university, research organisation and water consultancy staff can be embedded in working environments where good practices are routinely being applied; and investment in PhD level training, ideally embedded in or involving substantial collaborations with institutions that are recognised as global leaders in sustainable water management.

4.3. Mining company staff

The IM4DC activities gave us less information about the training needs of mine company staff compared to other groups. Nevertheless, the views of the participants and our other interactions with mining companies allow some informed comment. A clear training priority is monitoring the physical aspects of water management performance (e.g. volumes and chemistry of water discharges, seepage and evaporation rates). This must start with an understanding of and ability to clearly communicate how much

water is being abstracted to, consumed by, stored in, recycled within and discharged from mine systems. Therefore, we consider that training in mine water accounting and reporting is a priority. Many mine water managers would benefit from training in effective communication with communities, understanding the cultural and intrinsic values that these communities attach to water, and monitoring community satisfaction on water issues. Furthermore, safeguarding social license requires broad understanding of IWRM and how to participate in an IWRM framework. We recommend that site level training addressing these issues is provided by teams of technical and social science experts, who themselves have a good understanding of local issues. At the corporate level of mine companies, staff may need training in how to develop and lead a water stewardship culture. We recommend that mine water management leadership training courses are offered, and that key aspects of water stewardship principles are embedded in more general leadership training programs.

4.4. Policy makers and regulators

Discussion of these needs in the IM4DC activities was dominated by the problems associated with small-scale and illegal mining. The diffuse and transient nature of these types of mining, the potential influence of local communities in dictating mining activity, and the difficulty of transitioning livelihoods away from this type of income reliance are some of the underlying obstacles to effective policy and its implementation. In terms of supporting policy development, there is often good knowledge of the generic water-related risks and the importance of managing them. Rather, the training priorities relate to implementing regulations and systems for disseminating knowledge of risks and technological solutions to communities and miners; and for building frameworks for cooperative agreements between small-scale and large-scale mining. For mining more generally, it was also considered that policy makers and regulators would benefit from training in designing and implementing IWRM approaches.

4.5. Community representatives

Community–company relationships and representation were identified as recurring issues. These issues revolved around themes of governance; knowledge transfer; community needs and cultural values associated with water; level of trust between industry, government and community; environmental impacts, and compensation. The drive for wealth creation and distribution draws the community to small-scale mining and the government to large-scale mining and it is recognised that governance frameworks are needed for both activities. Policies developed need to include local knowledge, while feedback on technical issues is provided by government, educational or industry representatives. Community representatives, or the community at large, are by necessity required to understand health risks from mine site pollution, how mines can manage water, negotiation and trading skills; and water law rights for the management of risk both on and offsite. Training and education programs need to address these issues including: strategies to better understand the social water context that mines operate in and to incorporate understandings into technical water management; the environmental/social/economic importance of leading practice rather than compliant water management; the importance of transparency/communication; and, teaching of technical issues to communities. Community representatives may also have significant influence over artisanal mining activity through direct involvement of the community and also through land governance arrangements. In these cases, it is a priority for training to be provided on use of mining methods and technologies that effectively

manage health, safety and environmental risks; but also to provide the community and government with the appropriate methods, tools and governance structures to ensure that enforceable regulatory and monitoring methodologies are developed and available.

5. Summary

Development of mining sectors in resource-rich nations provides opportunities for poverty alleviation and long-term socio-economic development. However, the history of such development illustrates the social, environmental and economic risks. Many of the risks relate in one way or another to water.

In several countries that have already experienced or are facing the prospect of rapid development of mining, capacity building in water management is urgent; however it is not always clear what the priority education and training areas or audience are. The IM4DC program of the Australian Government, run by The University of Queensland and The University of Western Australia, between 2011 and 2015 has included numerous activities that have contributed to understanding of education and training needs in the water area (among others). This paper has synthesised the experiences and outcomes from five projects into a set of priorities for education and training efforts over the next few years. These are as follows:

- *For university students.* Through course and project work within university degree programs, students should be enabled to develop informed views about mining's interaction with water resources; and to motivate the pursuit of careers that contribute to sustainable development through mining.
- *For university, research institution and consultancy staff.* We recommend extended secondments to organisations who can provide advanced level training on leading practice, and investment in developing specialist expertise for example through PhD level training in appropriately qualified institutions.
- *For mine site water management staff.* Training is required to develop understanding and enable consideration of the impacts of mine water management decisions on other water users, starting with the ability to effectively monitor physical and community aspects of performance. Understanding how to account for mine water inputs and outputs is at the core of this.
- *For corporate level mine company staff.* Leadership training is needed, focussing on development of a water stewardship culture and rolling out associated good practices.
- *For regulators and policy makers.* Training is required towards understanding of sustainability issues surrounding mining and implementing catchment water management frameworks; and towards improving the governance of small-scale mining.
- *For communities.* Education is needed towards understanding health risks from mine site pollution, how mines can manage water, and negotiation skills and rights.

It is anticipated that our conclusions about education and training priorities can be used to inform the planning of capacity-building activities in future mining-for-development aid programs.

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