Integrating competing water needs of mining and mineral processing with the environment, community and economic activity in a mining-dominated catchment

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Abstract

The mining sector is facing increasing regulatory and social pressures to demonstrate efficient use of water resources on both a local and catchment scale. This paper presents an integrated approach to mine water use and management, and highlights the need to consider the role of secondary water resources, fit-for-purpose water use and the essential requirement to monitor water quality, as well as quantity, in such integrated systems. It aims to provide a basis on which to identify key knowledge gaps that need to be addressed to move towards a new paradigm of water management in 'mining' catchments in increasingly water scarce environments.

Keywords: water catchment areas, flotation, water quality, water management

Introduction

Water is considered the top long-term global risk by the World Economic Forum (2016). With increasing global and local water requirements, demand now outstrips supply. To ensure ongoing development and stable economic futures, three approaches are key regards water: firstly, more efficient use of water, thereby reducing demand; secondly, mobilising new water resources, other than surface and ground water sources; and thirdly, integrating water demand and supply across competing needs within a region. In this paper, we explore the potential and value of an integrated approach using, as a scenario, the activities within a catchment serving mines and mining communities in a water-scarce developing world context.

In developing regions, a mine site forms a nucleus, drawing in migrants with its potential for jobs, wealth creation and development. Its arrival is super-imposed on an existing system of livelihood and economic activity, resulting in competing needs and shifting priorities. Considering this in the context of water, competing needs and trade-offs develop rapidly between the stakeholders. Within the regional scenario, a range of sub-systems within the region interact. These sub-systems include (i) the 'livelihood water needs' of local communities, (ii) those associated with community economic activity (including small scale agriculture), (iii) water requirements of the mine and mineral processing facility (process water), (iv) water use by the commercial agricultural sector and, (v) water uses of the towns in the catchment area, including the industrial sector.

Owing to the associated wealth and opportunity brought to a region by a new mine, it has typically taken centre stage with regards to management of water resources in the catchment (fig.1). Increasingly, through the system of water use licences, introduced as a national government intervention (South Africa) with the aim to achieve effective water management, a more integrated positioning has been developing. Very effectively, the need to obtain a social licence to operate, places water management as central to the mining operation's success. The mine now needs to show its social responsibility towards water use, not only in terms of reducing the use of potable water and improving water reuse / recycling, but also in trying to ensure that the local communities around the mine have access to potable water.

This paper discusses a changing framework of water use, identifies potential new water sources and investigates the potential for integrated water use, as well as identifying the extended knowledge required to achieve this. Knowledge of all stakeholders' water requirements, including "fit-for-use" water, is of major importance in developing new paradigms for water use which should, in turn, ensure that the water demands of all users within a catchment are met. By working with the entire catchment and understanding the catchment's water balance, it is more likely that the water demands of the catchment can be met, underpinning economic development and the achievement of acceptable quality of life in water-scarce communities.

Integrated use of mine water across catchments

Figure 2 introduces the evolution in thinking towards integrated water management across all stakeholders within the catchment, rather than independent consideration as an internal company-specific problem. Figure 2 shows that the water rights for the mine and its operations are firmly embedded in the integrated framework, as is the need to address water requirements across the catchment, particularly those of growing communities in the surrounding region.

Reduction of abstraction of fresh water is essential to reduce the water footprint of the mine, to avoid perceptions of water competition, to protect the environment and natural ecosystems and to win and protect the social licence to operate. Water supply may be drawn from numerous sources. Historically, abstraction from ground and surface water reserves were the most common. This was followed by transportation of water from adjoining catchments. Increasingly the 'used water' category is of interest for water supply. This serves two important functions. Firstly, focus on the quality of 'used water' is an important step in mitigating its pollution potential. Secondly, the treatment of used water to 'fit for purpose' positions it as a potential supply, thereby reducing abstraction or increasing supply or both. Traditionally such 'used' water has been considered within the mine's boundaries e.g. ash dam and return water from tailings storage facilities, as part of the water recycle from process. An integrated water management approach considering water sources, used water and water

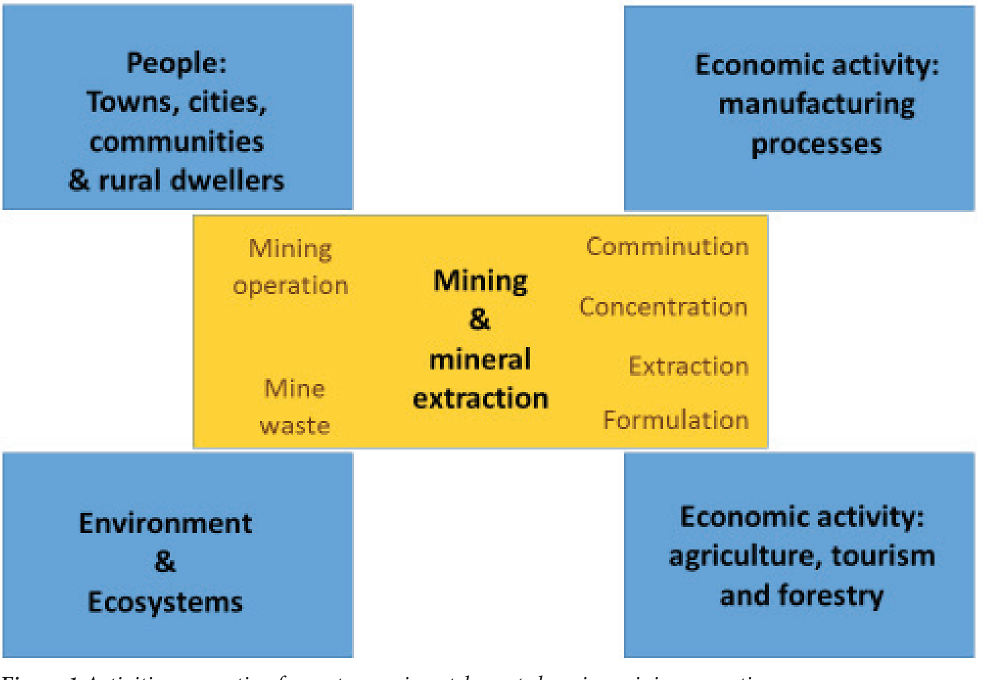

Figure 1 Activities competing for water use in catchments housing mining operations

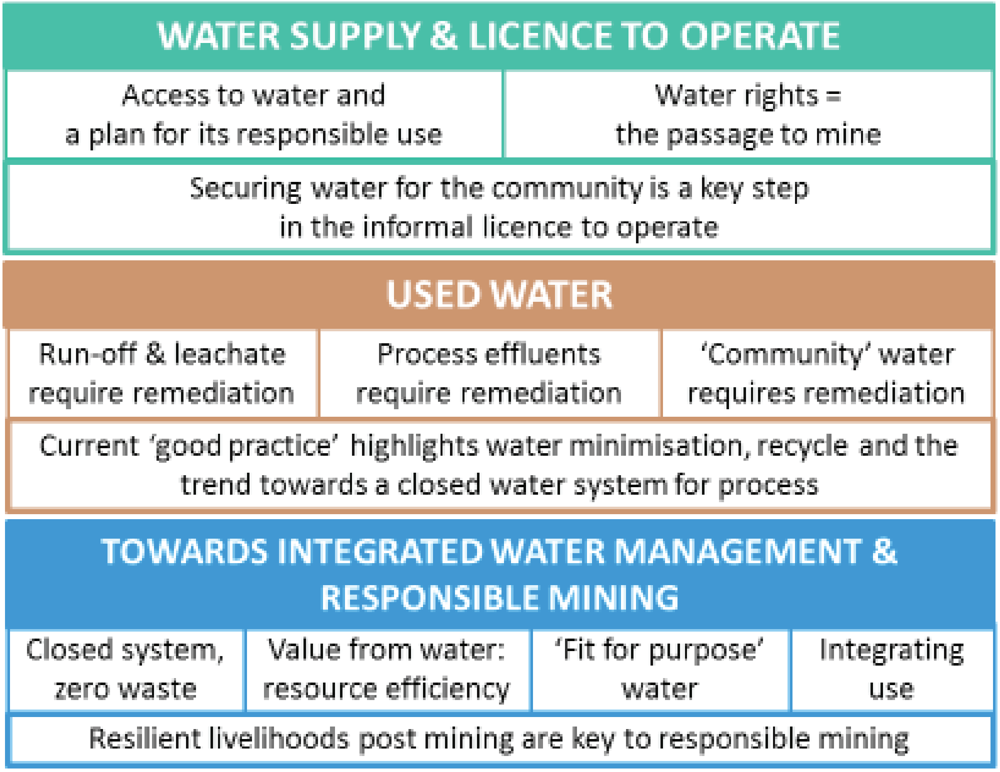

Figure 2 *Progression in approaches to integrated water management between mine, community and activities within the catchment*

demand across the whole catchment, giving cognisance to transport distances, allows for improved allocation of fit for purpose water with minimal additional treatment. Such revisioning of water management is developing rapidly in mining operations. For example, in South Africa some mining companies are contributing to the provision of clean water in water-stressed areas through the establishment collaborative partnerships with government and civil society. In the Mpumalanga coalfields of South Africa, acid mine drainage is treated in a water reclamation plant, supplying in excess of 30ml/day potable water to the local municipality (Gunther et al. 2006) , whilst the recently established Mine Water Coordinating Body (MWCB) aims to promote effective mine water management and re-use specifically through cross-sectoral and multi-stakeholder engagement and innovation. These approaches can lead to establishing trust and enhancing company reputation, ultimately reducing the risk of conflict and improving water security, and contributing to the social licence to operate.

Re-visioning water use in mining operations

Over the past 10 years, mining companies have focussed on water as a key enabler and thereby a key risk to their operation. Water impacts a mine's operation both directly and indirectly; the risk of water scarcity and water quality are direct impacts, while indirect impacts are the potential of open water systems to contribute to pollution and environmental challenges, and the perceived competition for water having potential to threaten the social licence to operate. Increasingly mine sites are working towards a reduced water footprint, through reducing the footprint of fresh water, by increasing the amount of water recycle / reuse (closing water circuits) and by assessing the potential for dry processing.

As an example, the developments in water sources for flotation may be considered.

Substantial research has been focussed on the impact of water quality on flotation as the mineral pulp processed through this concentration step comprises some 80 – 85% water (Levay et al. 2001). Water forms a key transporter and processing medium in the metallurgical plants. Increasingly this water is sourced from diverse sources, including *worked water* from the plant: such as recycle water from the thickeners, filters, de-watering units, internal recycle water from the float cells, and return water from tailings storage facilities (Muzenda 2010, Liu et al. 2013). Raw water includes water not previously used on plants such as borehole or ground water of varying quality, pit water, surface water, potable water, process water from surrounding industrial activities and treated sewage effluent (Liu et al. 2013). While traditionally, only raw water not previously used in any process was brought into the minerals processing operation as make-up water. Now, effluent water or treated effluents such as process water from surrounding industrial activities and treated sewage effluent are being utilised as make-up water to the process.

The quality of water is influenced by dissolved solutes such as detergents, organic carbon, hydrocarbons, metal ions, residual flotation reagents, dissolved oxygen, suspended solids and pH. Such components impact flotation through impacting hydrophilicity and hydrophobicity, metal exchange, pH, slurry viscosity, and froth stability, which in turn affect reagent usage and pH thereby impacting recovery, grade and mass pull (Muzenda 2010, Corin et al. 2011, Manono et al. 2013). While fresh water is typically acknowledged to yield the best performance, a consistent water supply facilitates development of a successful flotation protocol with good performance. The most challenging is a water supply of variable quality and quantity (Liu et al. 2013). Increasingly it is recognised that, by using separate reservoirs for differing water sources (separated wastewaters rather than directly mixing all waste streams), variability can be overcome to some degree by appropriate dilution, mixing and blending, provided water monitoring is available to inform the blending. Most importantly, the prior-year practice of mixing all waste streams as received, which simplifies the core process, is increasingly recognised as poor practice where water re-use is desired.

An example of use of blended 'fit for purpose' water sources for flotation is at Mogalakwena Platinum Mine, (Anglo American) in Limpopo, South Africa. Here treated sewage effluent, return water from tailings storage facilities and plant recycle water are blended to the required quality, thereby freeing piped potable water for community and other uses. Similarly, the new Ivanhoe platinum mine in the same area will utilise treated sewage effluent as process water. A benefit of using the treated sewage effluent is the investment of the mining houses in the upgrading of the sewage treatment works of nearby towns in order that they are able to supply the required volume at the required quality.

The ongoing challenge of meeting conflicting water needs is further demonstrated by Anglo American Platinum's recent commitment (March 2018) to deliver 3.5 million litres per day to communities in 42 villages surrounding Mogalakwena Mine in the Greater Mapela Region. This water will be produced from boreholes that will be sunk in the area. Anglo American Platinum has also committed to reducing fresh water abstraction by 50% in water scarce regions such as Limpopo (Mining Weekly 2018).

Similarly, in Peru, the Freeport-McMoRan Inc-owned Cerro Verde copper mine secured water for its major extension by constructing a wastewater treatment plant to treat 85% of the sewage produced from the 1 million people living in Arequipa; this sewage water was previously discharged to the Rio Chili river. The treated water equates to 1.8 m^3 s^{-1} and provides adequately for the plant extension, while also releasing clean water to the river, thereby aiding downstream agriculture (Fraser 2017). The cost and technical challenges of this project were substantial but this initiative of the mining company secured its own water needs, ensured health and safety through sanitation, re-vitalised the river and aided agricultural security by offsetting competition for water between farmers and the mine (Fraser 2017).

While acknowledging the great developments in knowledge of the impact of water quality on flotation over the past 10 years, Liu et al. (2013) highlighted the gaps in our knowledge base that constrain the use of, or performance with, non-conventional water sources in flotation. The impact of abiotic solutes on flotation has been broadly studied, however understanding the effect of biotic components remains very limited. Similar challenges are found in other extraction units e.g. leaching or bioleaching. Further, potential water sources for flotation and other aspects of mine operation are typically assessed starting with internal water sources. External 'fit for purpose' sources, rather than pristine sources, may provide great opportunities across an entire water system, with the added benefit of freeing up pristine water for other uses and eliminating or reducing release of low quality water streams to the environment. Typically the flotation process is adjusted to accommodate the water quality; equally, the water quality could be adjusted to accommodate its final use. Water quality monitoring has the potential to provide insight into what happens if water quality is varied. Monitoring may also allow for a seasonal change in reagent regime as water quality may be impacted by seasonal changes. Increasingly, it is recommended that water issues are addressed as part of the risk assessment.

Water quality as a key player

Requirements of water of differing quality based on its final use is well documented. In Table 1, this is clearly illustrated, showing the potential to select or blend to obtain appropriate sources matching application. The same is true for operations within the metallurgical processing train; however, these remain to be defined with equal clarity and will vary as a function of unit operation, active agents used, mineral ore processes etc.

Site-specific information is required for rigorous application of the approach while process specific information will provide a framework within which to identify key variables for consideration. Work is currently being performed at an Anglo American Platinum operation to understand which compo-

Table 1. Water quality requirements depend on application. Orange shading demonstrates the most stringent requirement. Concentrations are given as mg/l unless otherwise specified. For surface water and ground water, letters identify the application that defines specification of these guidelines (IRMA 2016).

Metal	Human health drinking water a	Water to Irrigate b	Aqua-culture water c (FW/ Mar.)	Aquatic organisms in fresh water d	Recrea-tion water	Surface water	Ground water
Aluminium	100	5000	30	55		30[c]	100[a]
Antimony	6		50 / 30			6[a]	6[a]
Arsenic	10	100		24	50	10[a]	10[a]
Cadmium	5	10			5	X[c]	5[a]
Chromium (tot)	50	100	[20 as Cr(VI)]		50	50[a]	50[a]
Copper	1000	200				[d]	200[b]
Iron	300	5000	10 / 10	300	300	10[c]	300[a]
Manganese	50	200	10 / 10	1700	100	10[c]	50[a]
Nickel	20	200	100/100		100	[d]	20[a]
Uranium (U^{238})	20 (1)	100 (0.2)		15		15[d] (1[b])	20[a] (1[a])
Alkalinity			20-100				
Chlorine	5	1	2	3	1	2[c]	1[b]
Chloride	250	100		120	400	100[b]	100[b]
CN (µg/l)	200		5 / 5	5	100	5[d]	0.2[a]
H2S			1 / 1	2	50	1[c]	
NO3	10	100	50 / 100	13	10	10[a]	10[a]
NO2	1	10	0.1/ 0.1	0.6	1	0.1[c]	1[a]
pH	6.5-8.5	6.5-8.4	6.5-9.0	6.5-9.0	6.5-8.5	6.5-8.4[+]	6.5-8.[b]
SO4	500	1000			400	400[e]	500[a]
TSS		30	40 / 10	15	30	15[d]	
TDS	500	1000			1000	500[a]	500[a]

nents of treated sewage water have negative or positive impacts on flotation.

Once these impacts are understood better blending techniques will be used such that as little as possible high quality water needs to be used, without compromising plant performance. In this case water monitoring is essential – particularly of the source water, as the blend may need to change if the source water quality improves or becomes worse.

Conclusions and key gaps for ongoing study

This study highlights the needs for and benefits of an integrated and holistic approach to water management within catchments in general, but specifically those home to mining operations. Through the use of an external frame of reference from the mine, which is both a water user and a (waste)water generator, a range of pristine and used water sources are available. By treatment to ‘fit for purpose’ for the needed task and optimised allocation to task, abstraction of pristine water sources can be reduced or, where scarce, retained for key uses such as human consumption.

The use of ‘fit for purpose’ water supply requires rigorous understanding of the impacts of components of the water stream, including minor components, on the process or activity, requiring such knowledge bases to be expanded and shared across activities such as agriculture, aquaculture, minerals processing, wastewater treatment, industrial sectors, and the local ecosystems amongst others. Our research will be extended to address the gaps identified towards developing this rigorous understanding.

Finally, by using circular economy and industrial ecology approaches, as appropriate, to water management, the integrated impact must be considered, especially that on ecosystems.

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