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Water and energy synergy and trade-off potentials in mine water management

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ABSTRACT

Reducing water consumption and increasing energy efficiency are emerging as two key requirements to move towards a more sustainable mining industry. However, the two targets can be in conflict as water management initiatives often lead to an increase in energy consumption. On the other hand, some water initiatives may lead to reduction in energy consumption, leading to synergy between energy and water efficiency initiatives. To maximise energy and water sustainability in mine water management, it is essential that synergy and trade-off potentials between the water and energy targets related to water initiatives are recognised.

Limited research has been conducted to develop a tool or approach to consider water and energy impacts of water initiatives in a coupled manner. This paper presents a protocol to recognise water-energy synergy and trade-off potentials. The protocol is demonstrated for three case study mine sites. The results of this paper show that a particular water management option can hold a synergy potential for one mine but a trade-off potential for another mine. The rigour of the approach captures cases where water management options are predicted to be synergistic, but are in fact shown to be a trade-off according to the results. It is concluded that the use of this protocol can provide insights about synergy and trade-off potentials between water and energy targets of mine sites subject to water management options. This is an innovative approach to more holistically assess water management option impacts.

1. Introduction

Water use and energy consumption in mining have been identified as two key business risks (WBCSD, 2009). Further, it is expected that the water risks for this sector are likely to grow as competition for access to water increases among all water users (Zabey and Boffi, 2009). The risks are due to predicted increasing water shortages, increased regulatory limitations on water use, as well as reputational and financial aspects. On the other hand, energy business risk relates to security and cost uncertainty which directly influence operational costs when assessing capital investment (Ghosal and Loungani, 2000; Koetse et al., 2006). The business risks associated with water and energy can cause production chain interruption, closing down of operations and increased remediation costs such as those related to water discharge and green house gas (GHG) emissions. Consequently, the risks can lower productivity and decrease economic activity of a region.

Water use and energy consumptions in the mining industry are large and increasing. Most mines use 0.4–1.6 kL of water per ton of ore feed (Brown, 2003). In Chile, the copper mining industry consumed 0.79 m^3 and 0.13 m^3 of fresh water to produce one ton of ore in concentration process and hydrometallurgical process respectively (Cochilco, 2008). Due to mining operation capacity expansions and uses of mass-mining techniques, especially with the increasing trend of super-cave mining, water demand for mining operations and mineral processing is increasing (Chitombo, 2010). In addition, the continuous decrease in grade of new ore deposits also leads to an unavoidable higher energy and water use, as more raw materials need to be processed to produce the same amount of final product (Mudd, 2009, 2010). Hunt (2009) suggested a range of factors including lower grade, greater haulage distance, shifting commercial product portfolio and technological change have made copper mining significantly more energy

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Key terms used in this paper

Aquifer	Reservoirs of underground water
Dewatering	Pumping water out of open pit and/or underground mining operations
Entrainment	Water that is contained in materials that are extracted and will be processed
Raw water	Water that is supplied or captured and has not been previously used for mine operations
Recycling	Worked water is treated before it is used in a task
Reuse	Worked water is passed to a task without transformation e.g. treatment
Runoff	Rainfall that falls on the site and/or outside the site that is collected and transferred to storages
Seepage	Water removed from the operational facility beneath storage or handling facilities
Stores	Facilities on site that hold or capture water
Tasks	Unit operations of basic steps in the mineral processing sequence
Task losses	Water disappears and/or is unavailable for other application after it is used at a task
Underground inflows	Groundwater that seeps into underground mining operation area
Water management option	Water solution that changes water system
Worked water	Water that has been used for mine operations and is returned to a store for future use

intensive in the second half of this decade. The same circumstances apply to other commodities as well.

Because water and energy are emerging as two key business risks for the mining sector, the two have become major considerations in the assessment of the sustainability. The increasing demands of water and energy use strongly affect mining companies' sustainability performance and production cost. Mining operations cannot exist without sufficient and secure supplies of both water and energy. For many mine expansion projects, access to water and energy has become a critical factor in assessing the feasibility of such projects. A good water and energy management strategy is essential for the success of a mining project throughout the life of a mine.

Due to the importance of water and energy, many initiatives have been conducted by mining companies to reduce water consumption and energy utilisation at mine sites. In general, management targets at mine sites are aimed at minimising energy consumption while maintaining sufficient water for mine operations. However, these two management targets are usually in conflict as water management initiatives often lead to an increase in energy consumption. An obvious example is the energy intensive reverse osmosis desalination process. Therefore, the assessment of water management options should consider water and energy impacts in a coupled manner to assist in the selection of alternative approaches for achieving a mine water management strategy.

Extensive research has been conducted to address the use and potential mitigation strategies for mine water and energy as isolated components of the mine water system. However, little is available on coupling water and energy management.

Most of water management research is about the topics of reducing mine water use and improving management. This research focuses on understanding independent aspects of mine water interactions, water and wastewater treatment, as well as water use efficiency. Among those, the predominantly studied aspects are impacts of mining voids on water resources and surrounding water bodies, e.g. groundwater table drawdown (Cidu et al., 2008; Kaergaard, 1978; Panilas et al., 2008) and groundwater contamination due to mining activities (Gandy and Younger, 2007; Razowska, 2001; Tonder et al., 2007; Younger, 2000). The effect of acid mine drainage (AMD) on the environment (Dinelli et al., 2001; Monterroso and Macías, 1998; Ritchie, 1994; Williams and Smith, 2000) is also extensively evaluated along with the required water and wastewater treatment to meet production and regulatory requirements (Levy et al., 2006; Madin, 2006; Pamukcu and Simsir, 2008). Recently, more research and projects have aimed at improving water use performance including increasing water reuse and recycling rates (Mathewson et al., 2006; Stegink et al., 2003), minimising water use (Bru et al., 2008; Consoli and Sills, 2000; Cote et al., 2010; Miller, 2003; Nappier-Munn and Morrison, 2003) and diversifying water supply options (Cochilco, 2008; Philippe et al., 2010; Stegink et al., 2003). A comprehensive conceptual model was also developed for mine water accounting and management (Cote et al., 2012).

Most research about mine energy use attempts to optimise energy efficiency at individual processing tasks so that less energy is consumed per ton of product. Even though some work has been expanded for energy efficiency in the mining sector, it is usually targeted at only task level that represents unit operations including basic steps in the mineral processing sequence such as grinding, leaching, flotation and dewatering. The main areas targeted for energy use improvement are comminution circuits (Napier-Munn et al., 1996; Pokraicic, 2009; Shi and Kojovic, 2007; Vogel and Peukert, 2004) and pumping systems (Munson, 2009; Rea and Monaghan, 2009). Some initiatives have been explored to identify the potential of improving energy use efficiency at site system level and regional level, such as by excess heat capture and recovery (Ziemski, 2007) and energy sharing between a mine site and its local community (Aguado et al., 2006). The use of renewable energy sources has also been considered (Driussi and Jansz, 2006; EPCM, 2013).

The interactions between water and energy in mining had limited attention until it was highlighted in the 5th World Water Forum 2009 in Istanbul, Turkey, and later in the Water in Mining Conference 2009 in Perth, Australia. Recently, the topic was specially addressed at the Gecamin 'Water in Mining' Conference 2012 in Santiago, Chile (Barrett, 2012). Two approaches developed to determine the energy requirements for different water strategies are: Optimal Mine Water Network Design using Water Pinch Analysis, and the Hierarchical Systems Modelling approach.

1.1. *Optimal mine water network design using water pinch analysis*

One of the first research initiatives relating to water and energy interactions in mining was the Mine Water Network Design (MWND) approach introduced by Gunson et al. (2010). Gunson et al. (2010) combined the MWND with the Water Pinch Analysis (WPA) approach and applied it to the mining industry. The WPA approach is a method used in other industries to identify a water allocation scenario within a water network that maximises water reuse and minimises wastewater discharge (CANMET Energy Technology Centre-Warennes, 2003; Hallale, 2002; Yoo et al., 2007). WPA has also been used in power plant applications to determine minimum energy consumption, operation costs and overall costs (Anantharaman et al., 2004; Assadi and Johansson, 1999; Manesh et al., 2008a, 2008b; Zhelev, 2005; Zhelev and Ridolfi, 2006).

The MWND approach firstly specifies quantity and quality of potential water providers (sources) and water receivers (users) within a mine water system. Energy demand for each potential water provider to be received by each potential water receiver is then identified. The energy demand includes energy required for water processes such as pumping, treatment, cooling and heating. In this way, energy requirement matrices of the water system are constructed. The MWND approach uses linear programming to select the matrix that requires minimum energy. As a result, an optimal water network which specifies which receiver is to obtain

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