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Evaluating the application of water footprint methods to primary metal production systems

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ABSTRACT

The methods available to calculate a water footprint of a product or process have developed significantly over the past several years. Recent methods recognise that there are two main impacts associated with water use: consumption and degradation, and these impacts can occur either directly at a production facility, or indirectly within a producer's supply chain. In this paper examples are provided showing how these methods can be applied to mining, mineral processing and metal production systems, with a particular focus on copper, gold and nickel production.

Water footprinting methods can be used in a variety of ways. The water stress index of different areas can be used to benchmark sites operating in different regions and to understand the water supply risks facing major mineral and metal commodities. The process of preparing a water footprint of an operation can also reveal significant opportunities for water savings at individual sites.

1. Introduction

National and international reforms, company commitment to industry sustainability and best practice codes, investors, governments and communities are all increasing the need to better understand the nature of interactions with water resources. In Australia, companies frequently report on their water use using a range of mandatory and voluntary corporate reporting schemes including the Global Reporting Initiative (2013a, 2013b) and CDP Water (CDP, 2013).

Life-cycle assessment (LCA) is an internationally standardised framework for assessing environmental impacts of products and processes (ISO, 2006). LCA provides a means of understanding both direct impacts occurring at individual production sites, as well as indirect impacts associated with processes occurring in supply chains. Generally, applications of LCA to mining and primary metal production systems have focussed on issues such as quantifying energy consumption and greenhouse gas emissions (Norgate and Jahanshahi, 2010; Eckelman, 2010) or developing measures of resource depletion (Klinglmair et al., 2013). In contrast, there has been few studies that have considered both the direct and indirect water use of these production systems (e.g. Haggard et al., 2013; Norgate and Lovel, 2006; Norgate et al., 2010; Olivares et al., 2012; Peña and Huijbregts, 2013).

This study describes the advances in life-cycle based water accounting methods and how they can be applied to understand the primary production of metal products, with a particular focus on copper, gold and nickel production.

Historically, water management within industry has primarily focused on maintaining local water security and ensuring compliance with water quality guidelines, with very little recognition of the impacts of indirect water use associated with supply chains. Improved understanding of the indirect water requirements of processes, along with an understanding of regional water contexts, creates opportunities for decision makers to consider impacts and risk factors associated with the use of water in their processes and supply chains.

A secondary goal of the study is to improve recognition within the LCA community of the variability of impacts that occur due to mining, mineral and metal production processes. The interactions and impacts of these processes can be very site specific due to a wide range of factors that include geology, topography, hydrology and climate. Failure to consider these impacts can lead to a poor understanding of the variability of impacts between production sites. Given that cradle-to-gate systems – such as primary metal production – are basic building blocks for many LCA studies, there is a clear need to provide high quality analysis of these systems.

Abbreviations: CWU, consumptive water use; DWU, degradative water use; WSI, water stress index.

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2. Water footprint assessment methods

2.1. Methods for quantifying water use impacts

The life-cycle based methods available to quantify the impacts associated with water use have been continually evolving over the past decade. Currently an international standard specifically for water footprinting is under development by the International Organisation for Standardization (ISO, 2013). This standard aims to provide a framework to ensure consistency in the way that water footprints are conducted and presented, while also reinforcing the need for a life-cycle approach. There are four basic stages of this type of assessment: goal and scope setting, life cycle inventory development, life cycle impact assessment, and interpretation of results.

There are several different methods available for conducting water footprints available in the literature (Kounina et al., 2013). For instance Hoekstra et al. (2009, 2011) have developed a method that considers water use in three categories: blue water use (freshwater), green water use (rainfall), and grey water use (water required to dilute discharged water to background pollutant concentrations). Several studies have applied Hoekstra et al.'s methodology to the minerals industry and identified limitations of the method (e.g. Olivares et al., 2012; Peña and Huijbregts, 2013). For instance the grey water calculation procedure cannot account for discharge of pollutants that have no background level in the receiving water. The current methods all have advantages and disadvantages in the way that they account for water use and water quality.

For this study we will primarily evaluate the water footprinting method proposed by Ridoutt and Pfister (2013a), that to our knowledge has not been applied previously to the minerals industry. This method is based upon the concept that there are two main impacts arising from water use. The first aspect is associated with the knowledge that the impact of physical depletion of water within a store or catchment varies with local water scarcity, while the second aspect is that degradation of water systems can occur due to changes in water quality. When expressed in terms of the same unit, these two aspects can be combined to estimate the 'water footprint' for a product or system. The development of this method from prior studies is shown in Fig. 1, with further description provided in the following sections.

2.2. Consumptive water use

Consumptive water use (CWU) is defined as a reduction in the volume of water contained within a water store. To account for regional differences in water availability, CWU estimates are converted to a reference unit, H_2O-e, using the characterisation procedure shown in Eq. (1). The unit H_2O-e (water equivalent) represents the global average impact caused by the consumption of 1 litre of freshwater. This representation is similar to the approach taken with greenhouse gas emissions that are reported in-terms of carbon dioxide equivalent (CO_2-e), where each individual substance that is emitted undergoes characterization procedures to convert it to this common unit.

$$\mathrm{CWU}\ (\mathrm{H_2Oe}) = \sum_i \frac{\mathrm{CWU}_i \times \mathrm{WSI}_i}{\mathrm{WSI}_{global}} \tag{1}$$

where CWU_i is the change in volume water contained in a store or catchment; WSI_i is a region's water stress index (refer to Pfister et al., 2009); WSI_{global} is the global average water stress index of 0.602.

The water stress index (WSI) for an individual region is calculated based upon the water withdrawals of different end users within the region, the available water in a region and the seasonal variability of this availability through time (Pfister et al., 2009). The results of this are normalised between 0.01 and 1 using a logistic function to produce the final estimate of a region's WSI. A high WSI may indicate that water demand is exceeding sustainable supply for a region, whereas a low WSI indicates there is relatively little water demand in an area and/or that the sustainable supply capacity is quite large.

2.3. Degradative water use

Degradative water use (DWU) represents the impacts that occur as a result of changes in the quality of water that are attributed to the process or product. DWU, in terms of H_2O-e, is derived by comparing the impacts associated with a production system to the global average impact for 1 litre of CWU. This is calculated using the ReCiPe 2008 impact assessment methodology that provides estimates of the potential impacts of a system on human health, ecosystems and resources (Goedkoop et al., 2009).

$$\mathrm{DWU}\ (\mathrm{H_2Oe}) = \frac{\text{RECIPE points (emissions to water for product system)}}{\text{RECIPE points (global average for 1 litre of CWU)}} \tag{2}$$

where ReCiPe points (global average for 1 litre of CWU) = 1.86×10^{-6} ReCiPe points (Ridoutt and Pfister, 2013a).

For this study we have calculated DWU based upon separate global averages for impacts to human health, ecosystems and resources, rather than the combination of all three. These are 7.05×10^{-8} points/m^3, 8.46×10^{-11} points/m^3 and 1.86×10^{-3} points/m^3 respectively (supplementary information of Ridoutt and Pfister, 2013a).

2.4. Single-indicator water footprint

A single impact indicator for water use or a water footprint can be defined simply as the sum of CWU and DWU (Eq. (3)) (Ridoutt and Pfister, 2013a).

$$\text{Water Footprint}\ (\mathrm{H_2Oe}) = \mathrm{CWU}\ (\mathrm{H_2Oe}) + \mathrm{DWU}\ (\mathrm{H_2Oe}) \tag{3}$$

These water footprint estimates provide a broader description of the impacts associated with a production system and aims to aid decision making by presenting information in a simple, directly comparable way that can account for both direct and indirect water use issues. It is anticipated that the consolidation to a single-indicator impact assessment can obscure specific impacts, and the method is also not appropriate for presentation alongside information relating to other impact categories such as toxicity, because it would result in a situation of double counting.

3. Water footprint inventory development

Water footprint inventories are an account of the significant inputs and outputs of water to a process. This paper presents water footprint inventories for several different copper, gold and nickel production systems based upon previous work by Northey and Haque (2013). These inventories are used to provide indicative CWU estimates for each process.

Inventory requirements for determining DWU require emissions to water for a system to be known. These emissions are very site specific and separate inventories have been provided for sites where data was available. Due to the site specific nature of water quality impacts for these production processes, the data is not included within the generic inventories for the production processes considered for the CWU estimates.