Danoucaras, Anastasia, Woodley, Alan, & Moran, Chris
(2014)
The robustness of mine water accounting over a range of operating contexts and commodities.
Journal of Cleaner Production, *84*(1), pp. 727-735.

The robustness of mine water accounting over a range of operating contexts and commodities

A N Danoucaras[1], A P Woodley[2], C J Moran[3]

[1]Postdoctoral Research Fellow, Centre for Water in the Minerals Industry, Sustainable Minerals Institute, The University of Queensland, St Lucia, 4067

Corresponding author: Anastasia Danoucaras.

Email: a.danoucaras@uq.edu.au

[2]Postdoctoral Research Fellow, Centre for Water in the Minerals Industry, Sustainable Minerals Institute, The University of Queensland, St Lucia, 4067

Present Address: School of Electrical Engineering and Computer Science, Science and Engineering Faculty, Queensland University of Technology, Brisbane 4000, +617 3138 0522,

Email: a.woodley@qut.edu.au

[3]Director, Sustainable Minerals Institute, The University of Queensland, St Lucia, 4067.

Email: chris.moran@uq.edu.au

Paper submitted to: Journal of Cleaner Production special issue on "The sustainability agenda of the minerals and energy supply and demand network: an integrative analysis of ecological, ethical, economic, and technological dimensions".

Abstract

Communicating the mining industry's water use is fundamental to maintaining its social license to operate but the majority of corporate reporting schemes list indicators. The Minerals Council of Australia's Water Accounting Framework was designed to assist the minerals industry obtain consistency in its accounting method and in the definitions of terms used in water reporting. The significance of this paper is that it shows that the framework has been designed to be sufficiently robust to describe any mining/mineral related operation. The Water Accounting Framework was applied across four operations over three countries producing four commodities. The advantages of the framework were then evident through the presentation of the reports. The contextual statement of the framework was able to explain contrasting reuse efficiencies. The Input-Output statements showed that evaporation was a significant loss for most of the operations in the study which highlights a weakness of reporting schemes that focus on discharge volumes. The framework method promotes data reconciliation which proved the presence of flows that two operations in the study had neglected to provide. Whilst there are many advantages of the framework, the major points are that the reporting statements of the framework, when presented together, can better enable the public to understand water interactions at a site-level and allows for valid comparisons between sites, regardless of locale and commodity. With mining being a global industry, these advantages are best realised if there was international adoption of the framework.

Keywords

Water accounting

Sustainability reporting

Water reporting

Mining

1 Introduction

There are many potential water problems associated with mining: acid mine drainage, pollution of groundwater due to seepage of tailings, mine water discharges into surface water and competition for water from other industries and the local community, to name but a few. Additionally, mining has water management strategies that are uncommon in industrial factories. Mine sites may collect rainfall and runoff in large water storages, withdraw water in excess to their needs due to ore body dewatering and recirculate large volumes of used water to meet water demands for ore processing and dust suppression. It is clear that mine sites often 1) interact with water flows to and from the environment and 2) recirculate their internal flows. It is very important to distinguish between internal and external flows in order to properly account and report mine water use. Flows to and from the environment must be delineated from internal flows to facilitate catchment level reporting. An understanding of the recirculation of internal flows is needed to understand the differences between the following volumes: water withdrawn, water consumed and water sent to tasks. Sometimes these different concepts are all termed 'water use' (GEMI, 2010) even though within the mining industry, they may have different volumes due to the presence of water storages and incidental take from ore body dewatering.

It is worthwhile at this point to clarify the terms water accounting, water reporting and lists of indicators since they serve different purposes. Accounting reconciles data, reporting presents the data and indicators are metrics that have been defined for benchmarking purposes. The paper will show that the problem with calculating indicators or reporting water volumes without first creating a fully reconciled water account is that flow volumes may be missed. The subsequent metrics or results that are reported will then be flawed thus they can no longer be considered benchmarks.

Arguably the Global Reporting Initiative (GRI), which consists of lists of metrics related to sustainability, is the most widely reported initiative in the mining industry (Brown et al., 2009; Fonseca et al., 2013). The GRI has three quantitative indices related to water; EN 8 water withdrawals, EN 22 water discharged and EN 10 water recycled and reused by the organization (GRI, 2013). Some authors have raised problems with the indices. Mudd (2008) attempted to use indicator EN 8, water withdrawals, to establish relationships between water volumes withdrawn and commodity mined. Even plants in similar climates, with similar designs, did not show relationships, which Mudd believed to be a problem with the mines' interpretation of the indicators. Indicator EN10 includes rainwater and whilst rainwater mitigates reliance on other water sources, it cannot be considered to be 'reused water' (Cote, Cummings et al. 2012). Perhaps in deference to the understanding that the GRI does not provide an accounting method (Morrison and Schulte, 2010), the fourth generation of the GRI (2013) guidelines G4 has added the requirement that reporting organisations must specify the standards and methods they use when reporting. Even if the indicators were better defined, researchers are questioning the usefulness of water data that is aggregated from many sites. Leong et al. (2014) argued that because water is context specific, the public needs site-level data to understand a particular mine site's interaction with the environment.

In contrast to the GRI, the water footprint is based on a sound, well documented method for water accounting and terms are defined. A mining company as a supplier of raw material may have to provide the blue water footprint of its processing step to its customers. The blue water footprint of a process step has been defined as the quantity of water drawn from surface water and groundwater that does not return to the catchment it was taken from in the reporting period (Hoekstra et al., 2011). Even though guidance has been provided in *The Water*

Footprint Assessment Manual with respect to the flows to include, the paper shows that it is still possible to under-report to the Water Footprint Network if a reconciled water account is not created first.

The Minerals Council of Australia (MCA) is funded by member companies which represents 85% of Australia's mineral production (MCA, 2013). The MCA along with the Centre for Water in the Minerals Industry developed the Water Accounting Framework (WAF) (Cote et al., 2012). Instead of lists of metrics, the WAF provides a method to ensure that internal flows are accounted for and flows to and from the environment are balanced against the change in water store volumes. In consultation with industry, the framework developers defined a list of water inputs and water outputs. Definitions for raw, worked and treated water were developed which then enabled consistent definitions for reuse and recycling efficiencies to measure internal recirculation of flows. Methods for the calculation of reuse and recycling efficiencies were developed, to ensure that precipitation and runoff, ore body dewatering and other raw water flows were conceptually removed from the reuse and recycling efficiencies thus improving on the GRI description. Thus the drivers behind the development of the WAF were to assist the minerals industry create a reconciled water account, obtain consistency in definitions, and address the problems identified with the definitions of the then G3 GRI indicators, which are unchanged in the current G4 guidelines. Locally there was also the need to help the minerals industry report to the Australian Water Accounting Standard 1 (WASB, 2012).

The MCA board endorsed the WAF's Input-Output model in 2011, thus the uptake of the framework has been good as most mining companies in Australia are required to report the Input-Output Statements. With mining being a global industry, the reasons for creating the framework: for standardisation of terms to improve comparisons across sites and companies, simplifying communication of water accounts to the public and improving the consistency in reporting to other voluntary initiatives, are even more relevant. Attempts to increase the profile of the framework internationally have occasionally raised initial concerns that because the framework has been developed in Australia, it may not apply to a site's operating context, its region or the company's reporting metrics. These concerns are due to a misunderstanding of the role of the framework.

The developers of the framework have designed it such that once the initial water account is created; it enables further reporting to other corporate level water reporting initiatives such as the GRI and the water footprint network (Danoucaras et al., 2013; Osman et al., 2013). Regarding whether the WAF will apply to a particular region, the WAF has been designed so that it is academically rigorous and can be applied to any site, regardless of commodity and location. The developers designed the framework to ensure that the accounts include enough information to enable reporting to academically rigourous regional accounts such as the Molden and Sakthivadivel (1999) water accounting framework. To be compliant with the Molden and Sakthivadivel framework, the reports must contain separate reporting of groundwater and surface water, the change in water storage, other outputs besides discharge such as evaporation, water to the sea, pollution, and incorporation into a product. All this information is contained in the WAF. The global minerals industry itself will benefit from a method to create water accounts with standard definitions although it is acknowledged that reporting to the framework does not replace compliance or legislative reporting.

The paper demonstrates that the framework developed by Cote el al. (2012) can be applied across different commodities in different environments and can therefore, promote consistency in reporting globally. To illustrate the WAF flexibility, the study created water accounts of four different commodities in three countries that operate in different climates to show that a wide range of inputs, outputs and tasks can be described under the definitions of the framework. The different commodities that were compared were: a coal mine in Australia (Site 1), an iron ore mine in Australia (Site 2), a copper mine in South America (Site 3) and a platinum mine in South Africa (Site 4). To avoid the possibility of identification of the sites, the particular region will not be revealed; although the contextual statements of the operational facilities will reveal climate and geographical features that are necessary to understand the results of the water accounts. The discussion will show the aspects of the reporting statements that the public can draw upon to understand the impact of a mine site on the water sources in a region.

2 Methods

A description of the Water Accounting Framework has been published within the book *Water Accounting: international approaches to policy and decision-making* (Cote, Cummings et al. 2012). The procedure for creating a water account and for obtaining reuse and recycling efficiencies have been given in greater detail in other literature (MCA, 2014; Woodley et al., 2013) but the salient points of the framework and method are reproduced here to demonstrate how the Water Accounting Framework reporting statements are based on fully reconciled water accounts.

Identify the boundary

An operational facility is the water reporting entity. Operational facility is the term used as it may be a mine site or/and a processing plant, a port operation – it encompasses any minerals handling facility. The boundary drawn around the operational facility depends on the company's needs. The boundary may be equivalent to the physical site boundary but as it is a conceptual boundary, there are times when a site may choose to extend the boundary, to include off-site facilities for which the site holds responsibility for, such as a camp.

Two conceptual models underpin the framework as shown in Figure 1; The Input-Output Model, which represents interactions between an operational facility and its surrounding community and environment (solid lines), and the Operational Model, which represents the interactions within an operational facility (dashed lines) (modified from DRET 2008).

<Insert Figure 1 here>

Figure 1 - The conceptual models that underpin the Water Accounting Framework

Identify the water inputs

Water inputs are volumes of water that enter the operational facility from a source external to the boundary. Inputs consist of: surface water flows such as those from rivers and lakes; water flows that can't be seen such as water entrained in the ore to be processed and water received directly from the environment such as rainfall, runoff, snowmelt and groundwater accessed during dewatering of an ore body. Note that even though the ore body dewatering may occur within the mine site lease, the water comes from the environment and cannot be considered an internal flow of the operational facility. Inputs are reported with their source of which there are four categories as defined in Table 1 (Cote et al., 2012). The account developer can work down the list and modify the inputs as necessary to suit the particular configuration of the operational facility but the source categories are defined and set: surface water, groundwater, sea water and third party water.

Table 1 List of inputs with their corresponding sources

<Insert Table 1 here>

Identify the water outputs

Water outputs are volumes of water that exit the operational facility to a destination external to the boundary. Outputs consist of: surface water flows such as discharges to rivers and lakes; water flows that can't be seen such as water entrained in the product or waste material and water sent directly to the environment, such as seepage and evaporation. There are five destination categories for the outputs: surface water, groundwater, seawater, third party water and other (includes evaporation, entrained water in products and tailings, task losses) and are provided in Table 2. As with the inputs, the account developer can modify the list of outputs as necessary but the destination categories have been defined and cannot be changed.

Table 2 List of outputs with their corresponding destinations

<Insert Table 2 here>

Separate Diversions from Site Inputs and Outputs

The next step of the Input-Output Model is to separate diversions from the flows that interact with onsite activities. Diversions are volumes of water that are actively managed by the site but the water is not used or intended to be used for any of the tasks within the operational facility as shown in Figure 1. For instance, constructed river and creek diversions are commonly found in mining however the volumes flowing down the river or creek do not need to be reported for the WAF as the flows are not actively managed by the site on a day-to-day basis. Some examples of reportable diversions under the WAF include: water that is dewatered as part of the extraction process and then recharged to an aquifer; water that is taken from a river and returned at an appropriate time to sustain environmental flow or rainfall and runoff that is supplied to a community for beneficial use. It is possible for diversions to be held in on-site storages but the diversion inputs must equal the diversion outputs because of the requirement in the WAF that site inputs less site outputs equal the change in site storage.

Determine the water quality categories of the inputs and outputs

Water quality categories have been defined by the framework. Figure 2 is a decision tree used to determine the category of the water.

Category 1: Category 1 water is of a good quality and would require minimal and inexpensive treatment (disinfection) to make it suitable to meet drinking water standards.

Category 2: Category 2 water is of a medium standard and the individual constituents can encompass a wide range of values. It would require moderate treatment such as disinfection, neutralisation, removal of solids and chemicals to make it suitable for drinking water.

Category 3: Category 3 water is of a poor quality. High values of total dissolved solids or harmful levels of dissolved metals or very high/low levels of pH place water in Category 3. This is due to the treatment required; the most energy intensive treatment processes are those dealing with the removal of dissolved solids including metals. It is difficult to modify the pH of large volumes of water found in dams or mine water storages.

<Insert Figure 2 here>

Figure 2 - The decision tree used to select a water category for a water input or output

Determining reuse and recycling efficiencies

The mine site configuration is represented by a systems level diagram, which greatly simplifies the water balance. Tasks are operational activities that use water. The choice and number of them is completely flexible depending on the activities of the mine site or operational facility. To enable the calculation of the site's recirculating flows, the systems level view shows the site's internal flows such as task demands, flows from tasks that are returned to the process and flows in and out of water storages. Tasks do not store water so data reconciliation is possible at task level. To avoid inadvertently identifying the sites, the systems level diagrams of the case study sites are not shown.

Water is said to have one of three statuses (raw, worked and treated worked). Raw water does not necessarily mean high quality water; it simply means that the water has not been used in a task on-site. Worked water is water that has been used at least once in a task. Treated worked water is water that has been used on-site than processed through a water treatment plant. Acceptance of the water status definitions allows reused and recycled water to be defined. Reused water is the worked water that is sent to a task (Equation 1). Recycled water is worked water that has been treated and is sent to a task (Equation 2).

$$\text{Reuse efficiency} = \frac{\text{Sum of worked water flow volumes to tasks}}{\text{Sum of all flow volumes to tasks}} \qquad \textbf{Equation 1}$$

$$\text{Recycling efficiency} = \frac{\text{Sum of treated worked water flow volumes to tasks}}{\text{Sum of all flow volumes to tasks}} \qquad \textbf{Equation 2}$$

Calculating the sum of worked water flows to all tasks is not as simple as measuring the water flow from the process water dam to the tasks because not all the water in the process water dam is worked water. It will likely also hold raw water, often in in the form of rainwater and runoff but potentially water from other inputs such as river withdrawals or dewatering. The term used in the framework is the 'mixed water store' to emphasise this. The proportion of worked water in the mixed water store must be calculated and is determined by assuming it to be the same as the proportion of worked water entering the store over the course of the reporting period, assuming perfect mixing. This is not strictly true as the proportion will change daily over the course of a reporting period depending on rainfall events or changes in volumes of ore body dewatering. However the simple approximation is sufficient and is better than assuming the entire volume of water from process water dams sent to tasks is worked water. The method is a simple way of conceptually removing the raw water proportion in the store.

The tailings storage facility (TSF) has been defined as a task rather than a water store to reflect that its role is to contain waste material thus the reclaimed water is included in the reused volumes. It is acknowledged that some sites do store water in their tailings storage facility and the above method can be applied for removing the proportion of raw water in the TSF to not inflate the reused volumes (MCA, 2014).

The reporting period depends on the account developers but in this paper, the reporting period was a year for each site.

3 Results

The full set of reports under the Water Accounting Framework is the:

- Contextual Statement;
- Input-Output Statement;
- Accuracy Statement; and
- Statement of Operational Efficiencies.

The contextual statement provides information to place the water accounts within the environmental and social background of a region.

The Input-Output Statement consists of two tables – the Input-Output Table and the Diversions Table. The Input-Output table is an itemised list of site inputs by source and water quality category; and site outputs by destination and water quality category. The Diversions Table also lists diversion inputs and outputs. The detailed information of the Input-Output Tables can be summarised so that the input flows are recorded against source categories and the output flows are recorded against the destination categories.

The accuracy of accounts is communicated through the accuracy statement, which shows the proportions of flows by volume which are measured, estimated or simulated and the confidence in the quantification of each flow volume.

The statement of operational efficiencies presents the percentages of water reused and recycled against task demands.

Whilst all four statements contribute to the water account, the purpose of the paper is to show the WAF's flexibility, therefore, particular emphasis has been placed upon displaying the Input-Output Summary (Table 3) and the Statement of Operational Efficiencies (Table 4) for each case study. The Input-Output Summary is the summary information of the full Input-Output statements, the details of which are in Table 5 - Table 8.

3.1 Contextual Statements

The purpose of the Contextual Statement is to provide background information about the water resources of the operational facility as well as any conditions that have an impact on the management of those water resources. In general, contextual statements are to contain a description of the climate, the geography of the location of the operational facility, information that assists in understanding the representation of the operational facility such as a list of the tasks, information that assists in understanding the water accounts and social contextual information such as a list of stakeholders surrounding the operational facility. To understand the numbers reported in the Input-Output statements and the Statements of Operational Efficiencies, they must be linked to the context of the mine therefore shortened versions of the Contextual Statements have been supplied in Section 3.1.

3.1.1 Contextual statement for Site 1, a coal mine in Australia

The reporting period was 19th November 2008 to 18th November 2009.

The annual rainfall for the reporting period was 455 mm. The long term average was 660 mm/year. Most of the rainfall and runoff was caught and stored but a small amount of mine affected runoff was diverted via sediment ponds.

The final storage volume for the reporting period was known to be 13,900 ML. The change in storage was calculated to be a 1873 ML loss found by subtracting the volume of outputs from the input volume. Thus the storage at the start of the reporting period was calculated to be 15,773 ML which reflects the storage level that the mine site was maintaining at the time - between 15,400 ML and 15,800 ML.

The following tasks were identified: Coal Handling and Processing Plant (CHPP), truck fill, CHPP washdown, vehicle washdown and the tailings storage facility. There was reclaim of water from: the thickeners of the CHPP, the washdown of the CHPP and vehicles and decanting of the tailings storage dam to the mixed store.

For three months towards the end of the reporting period, the tailings dam was used to store a nominal amount of water of around 1,000 ML. Since this storage was only 7% of the total mine water inventory and for three months of the year's reporting, it was decided that this storage was immaterial and the tailings dam for the purposes of the WAF could be considered a task.

There was a water treatment plant on-site but the water from it was not sent to tasks so the recycling efficiency was zero.

3.1.2 Contextual Statement for Site 2, an iron ore mine in Australia

The reporting period was from the 1st July 2010 to 30th June 2011.

The water supply was from groundwater, mainly the dewatering of the ore body (10,244 ML/year out of a total of 10,325 ML/year). Some of this water was supplied to tasks and then lost, with the remainder discharged to a creek.

There was no rainfall or runoff collection because there was excess water from ore body dewatering. The annual rainfall for the reporting period was 545.6 mm. The 15 year average annual rainfall was 407.7 mm. The rainfall and runoff flows were diverted via sediment ponds. The catchments of the sediment ponds were not provided in the supplied report so no estimate can be given of diversion flows.

The following tasks were identified: dust suppression, potable supply, process supply, construction and earthworks, exploration and drilling. There was no water reclaim from tasks so the volume of reused water was zero.

3.1.3 Contextual Statement for Site 3, a copper mine in South America

The reporting period was from the 1st July 2010 to 30th June 2011.

Site 3 was comprised of an open pit mine with an associated leaching process, solvents extraction and electro-winning. The operation was located in a desert region and so the site received very little rainfall. There was no long term storage of water.

Tasks were the waste rock dump, heap leaching pads, solvent extraction and electro-winning, campsite, plant use, dust suppression, and a small amount of other miscellaneous uses. There was reclaimed water from the waste rock dump, heap leaching pads and the solvent extraction and electro-winning process.

The unknown flow in the Input – Output Statement in Table 4 was included in order for the account to balance against known flows indicating less than a 2% error in the account.

3.1.4 Contextual Statement for Site 4, a platinum mine in South Africa

The reporting period was from the 1st January 2010 to 31st December 2010.

Site 4 was a platinum mine that contains two concentrator plants. Most of the water input to the site (~50%) was waste effluent from a local community, considered to be third party supply under the WAF. The remainder came from groundwater and a significant volume of unknown flow of 1,256 ML that entered the concentrator plant. The unknown flow was added to ensure that the concentrator task balanced when representing the site in the systems level diagram. For the reporting period, the mine was temporarily allowed to discharge water to two local rivers. A small amount of water was supplied to the local community.

No climate data was available for the reporting period therefore long-term (97 year) averages were used. The typical climate for the region is hot and wet summers with dry winters, with most rain (85%) occurring in the six months between November and April. The annual evaporation (2,210 mm) is more than three times the annual rainfall (662 mm).

The onsite tasks were the concentrator plants, dust suppression, the tailings dam and vehicle wash down. The Tailings Dam had a decant flow of 55% to the mixed water store for reuse.

3.2 Water accounts for Sites 1 – 4

The water accounts in Tables 3-8 show that different sites and commodities report to the WAF with a consistent format. Hence the points describe the information in the tables but do not constitute broad generalisations that the results found were typical for that commodity. Results are compared to each other to illustrate what information can be gleaned from the tables, not for the purpose of benchmarking between commodities.

Table 3 shows that Site 1 mainly drew on high quality surface water, the main input for Site 2 was groundwater, Site 3 purchased water and Site 4 drew on a variety of input sources. The predominant output from the sites fell into the ‘other’ category therefore the Input-Output Statements of the individual sites must be referred to for further details. Table 3 shows that a flow volume came from an unknown source for Site 4, the volume of which was known from the WAF method of data reconciliation at the task level.

Diversions were recorded separately from the site inputs and site outputs for Sites 1 and 2 although volumes weren’t known for Site 2 because the diversion inputs or outputs were not measured or gauged.

Table 3 shows that Sites 2 and 3 did not store water over the course of the reporting periods.

Table 3 Input-Output summary table for Sites 1-4

<Insert Table 3 here>

Reused water is worked water that is sent to a task. Table 4 shows that site 4 had the highest task demand but also the highest water reuse efficiency at 68%. The task demands of the other sites were comparable to each other but reuse efficiencies varied from zero to 64%. No sites recycled water; with water recycling being defined in the WAF as the use of treated worked water in tasks.

Table 4 Statements of Operational Efficiencies for Sites 1-4

<Insert Table 4 here>

Tables 5-8 show the details within the source and destination categories of the inputs and outputs. Table 5 shows that Site 1 collected rainfall and runoff for use on-site with evaporation being a significant output.

Table 5 Input-Output Statement for Site 1, a coal mine in Australia

<Insert Table 5 here>

Table 6 shows that Site 2 withdrawals of groundwater were from dewatering with approximately equal proportions of the site output to evaporation, task loss and surface water discharge.

Table 6 Input-Output Statement for Site 2, an iron ore mine in Australia

<Insert Table 6 here>

Table 7 shows that the major site input for Site 3 was municipal water and the major site outputs were evaporation and water entrained in waste material.

Table 7 Input-Output Statement for Site 3, a copper mine in South America

<Insert Table 7 here>

Table 8 shows that Site 4 had a variety of sources that it drew upon with collection of rainwater, ore body dewatering and purchased water as well as a large volume of flow from an unknown source. Site 4 outputs were evaporation and task loss.

Table 8 Input-Output Statement for Site 4, a platinum mine in South Africa

<Insert Table 8 here>

4 Discussion

The flexibility of the framework means that any site regardless of its location or commodity can report to it. The source categories of the inputs (Table 1) and the destination categories of the outputs (Table 2) are fixed and are clearly defined. They cover all possible pathways of water transported across the site boundary including ones that are required but often neglected: water entrained in the ore to be processed, water entrained in the tailings that cannot be recovered, water in the product streams that leave the operational facility (Molden and Sakthivadivel, 1999). Although seawater was not an input or output for any of the operations in this study, there are sites that use seawater for flotation (Bournival et al., 2012; Castro et al., 2013) so it has been defined as a source category by the developers of the framework. Within the categories there was flexibility when describing the specific inputs and outputs that comprise each category as shown in Table 5 to Table 8 for the operations. Thus operations can report according to their specific configurations, but the WAF acts as a standard since it enables aggregation and comparison across operations by the source and the destination categories. Table 3 showed that there were unknown flows for Sites 2, 3 and 4 thus improving the transparency of information and providing impetus to the companies to close the information gaps.

Perhaps the reason why Mudd (2008) was unable to find a relationship between water withdrawals and commodity is because not all water that is withdrawn is required by the facility for its purposes. For instance, ore body dewatering is incidental take. In the WAF method if the water is not required by the operation and leaves the boundary, for example through re-injection, then the water is a diversion. It is clear in the WAF summary table (Table 3), which flows are inputs for the operation's needs and which are diversions because they are segregated in different tables within the Input-Output Statement. Instead of companies reporting to GRI G4 (2013) indicator EN 8 water withdrawals, it might prove more useful to report task demands as required by WAF; then it might be possible to establish relationships between water volumes and commodity for plants in similar climates with similar infrastructure.

Even though diversions may represent flows that are from incidental take, it is important that companies report diversion inputs and outputs because they are flows that are to and from the environment. It could be argued that the biggest risk to the comparability of the framework reports is discerning whether a flow is a site input or a diversion input. It could be reasoned that the portion of water that was discharged from Site 2 of 3654 ML (Table 6) represented a diversion because the water was in excess of the site's requirements. Furthermore the task demand of Site 2 was 6670ML which indicates that the discharge was excess water. If the water was stored with the intention that it was to be used for on-site purposes, the account developer may not have had enough information to remove that component from the site input volume. Thus the account developer has some freedom when deciding the table the flows should be reported within. However, because of the requirement that both the site Input-Output Table and the Diversions Table be presented in the Input-Output Statement, regardless of choice, the report promotes transparency.

The advantage of the Input-Output Statement is that it is a complete balance since all losses such as seepage, evaporation, task loss and entrained water in final products – (including waste material) are considered. Companies, probably due to having to report the GRI indicator G4 (2013) EN 22 total water discharge by quality and destination, have tended to focus their reporting on discharge quantities. For Site 2 which produced excess water, discharge was a third of the site output volume (Table 6) but for Site 1 (Table 5), Site 3 (Table 7), and Site 4 (Table 8), discharge was a small fraction of the site outputs. Discharge is only one type of output; to promote transparency and data reconciliation, all outputs should be reported such as evaporation, seepage and other water losses. The dominant output for the other sites was evaporation thus the reporting statement can highlight areas the mine sites can target should they wish to minimise losses.

Data reconciliation is provided through the Input-Output Statement because the site inputs minus the outputs must equal the change in storage over the course of the reporting period. For Site 1, the end storage volume of 13,900 ML was known and the starting volume of 15,773 ML was back-calculated based on the overall water balance. The initial value reflected the storage level that the mine site was maintaining at the time - between 15,400 ML and 15,800 ML. For Sites 2 and 3, the data reconciliation process was even clearer because these sites had no long term storage so the inputs had to equal the outputs (Table 3). Data reconciliation is also necessary at the task level. For both Sites 3 and 4 in Table 3 there were unknown flows that were apparent from the systems level diagram. The systems level diagram highlighted that tasks were unbalanced, indicating that data was missing. For Site 3 this flow was negligible at 36 ML but for Site 4, the South African platinum mine, this was a large flow of 1256 ML. Had there not been data reconciliation at both task and site levels, the reported site inflow for GRI EN 8 for Site 4 would have been 8342 ML which is much lower than the actual site inflow of 9604 ML. In a similar manner, if there had been unknown flows in the outputs list that did not get discovered through the water accounting framework method, a company would under-report the blue water footprint. These results promote the importance of applying the Water Accounting Framework method prior to reporting to other schemes and initiatives.

Comparing the site inputs and outputs in Table 3 with the task demands in Table 4 highlighted aspects of the water management system for the sites. For instance, Site 1 withdrew a volume that was comparable with its task demands. Site 2 which has already been discussed, withdrew in excess of its requirements due to incidental take from ore body dewatering. Sites 3 and 4 withdrew less than task demands indicating that water circulates around the site which affects the efficiency metrics.

There are only two indicators in the Water Accounting Framework – the reuse efficiency and the recycling efficiency. The guidance in the GRI G4 supplement advises that collected rainwater can be included in EN 10 (GRI, 2013) so sites that collect rainfall – Sites 1, 2 and 4 - will have inflated GRI reuse efficiencies. The WAF definition is superior because the water status definitions better reflect the origin of the water that flows to a task – outside the site boundary (raw) or an internal flow (worked). Similarly, the input of ore body dewatering was sometimes considered to be worked water prior to capacity building of the industry on the framework, since the water appears to originate from the mining task. There are two consequences with reporting: it may not get reported as a site input and it is considered 'reused water' when sent to a task. But the WAF acknowledges that the origin of the flow is from the environment and thus, cannot be considered an internal flow.

One critique of the framework is that the indicators reuse and recycling efficiencies, assume that the site is in a region of water scarcity. The value of the Contextual Statement is that it is useful to place the indicators into the environmental context of the region surrounding a mine site. For instance, across the four sites there were the following reuse efficiencies: 1) 35%, 2) 0% and 3) 64% and 4) 68%. Site 2 had excess water from ore body dewatering so the zero reuse efficiency is explained by the context. In contrast, Site 3, the copper mine and leaching plant was in a desert region, had low rainfall, purchased water and reclaimed as much water as it could, thus it had a high reuse efficiency. The coal mine site (Site 1) reuse figure of 35% was within the range of coal mine reuse efficiencies between 5 % and 70% of a previous study (Cote et al., 2008). The platinum mine (Site 4) had the highest reuse efficiency due to decanting a large volume of water from the tailings dam.

The paper has demonstrated the flexibility of the framework to represent operations in a consistent manner but we believe the biggest threat to the uptake of the framework is that companies are hesitant to provide individual site-level disclosure. Whilst we gratefully acknowledge the companies that allowed us to publish detailed water accounts, it was with the proviso that the operations were anonymous. One of the advantages of achieving consistency in terms is that once there is consistency on a global scale, companies can aggregate their water accounts and use it for communication in their sustainability reporting. But the authors of this paper strongly agree with Leong's (2014) viewpoint that water reporting is at its most useful when it relates to one operation rather than a company aggregate total. It may be cumbersome to present numerous accounts within a company level sustainability report but the details would be easy to publish on a website linking the Input-Output Statements with a map showing locations of sites.

The Water Accounting Framework strengthens reporting because the reports have a basis in water accounting thus the reports are more meaningful than lists of indicators. There are consistent definitions of terms to enable comparison between operations. The Contextual Statement ensures that comparisons are done with an understanding of the region however a discussion of benchmarking and best practice is outside the scope of the current paper. Application of the Water Accounting Framework in itself does not promote water efficiency gains but this does not detract from its purpose of promoting consistency in reporting because without a common platform, any benchmarking is susceptible to error.

The research significance of this work is broader than just achieving consistency across the mining industry. Applying the WAF at multiple sites within a region will assist broader level sustainability initiatives. The potential for regional accounting is raised in the article as it is an obvious application, but it is the subject of future research.

5 Conclusions

The contributions of this paper to the field of corporate water reporting were to show the ability of the Water Accounting Framework to create water accounts for varied sites and to highlight its advantages in its method, its definitions of terms and the format of its reports. The advantages of the Water Accounting Framework are useful for the mining industry on a global scale; therefore there should be international adoption of the framework.

The study demonstrated that the Water Accounting Framework had sufficient flexibility to represent water interactions and produce performance metrics of mine operations regardless of their location, climate and commodity because the choice of inputs, outputs and tasks were flexible within standardised definitions. The flexibility countered claims that the Water Accounting Framework could not be applied to operations outside Australia because sites have already aligned their definitions and created water balances to satisfy regulators or/and voluntary initiatives. The commodities presented were iron, copper, coal and platinum from sites operating in Australia, South America and South Africa.

The information contained in the reporting statements was a complete water account – inputs, outputs (not just discharge flows) and diversions. The method of the Water Accounting Framework allowed data reconciliation of flows. The importance of this was demonstrated by explaining that if water volumes are under-reported, the indicators of other initiatives are meaningless. This is true for the reporting of all industries, not only mining.

The paper explained that the method to obtain the reuse efficiency metric, conceptually removed raw water from the reuse volume. The background information contained in the contextual statement explained why the accounts differed, especially in the reported reuse efficiencies of the four sites. The contextual statement ensures that only valid comparisons between operations are made.

When the full suite of reports is presented for a particular location, it enhances the surrounding communities' ability to understand the operation's interaction with water. Furthermore in the future, when many sites in a region report the same way, regional reporting can be established which can enhance sustainability initiatives that are at the catchment level.

6 Acknowledgements

The authors of the paper gratefully acknowledge the companies that allowed the publication of the results.

7 List of Figure Captions

8 List of Table Captions

9 References

Bournival, G., Pugh, R.J., Ata, S., 2012. Examination of NaCl and MIBC as bubble coalescence inhibitor in relation to froth flotation. Minerals Engineering 25, 47-53.

Brown, H.S., de Jong, M., Levy, D.L., 2009. Building institutions based on information disclosure: lessons from GRI's sustainability reporting. Journal of Cleaner Production 17, 571-580.

Castro, S., Miranda, C., Toledo, P., Laskowski, J.S., 2013. Effect of frothers on bubble coalescence and foaming in electrolyte solutions and seawater. International Journal of Mineral Processing 124, 8-14.

Cote, C., Moran, C., Gozzard, E., Craven, A., Smith, J., 2008. Understanding Leading Practice in Water Management: Australian Coal Association Research Program Project C16035 final report, Centre for Water in the Minerals Industry, Brisbane. Available at http://www.acarp.com.au/abstracts.aspx?repId=C16035.

Cote, C.M., Cummings, J., Moran, C.J., Ringwood, K., 2012. Water Accounting in Mining and Minerals Processing, in: Godfrey, J.M., Chalmers, K. (Eds.), Water accounting: international approaches to policy and decision-making. Edward Elgar Publishing Limited, Cheltenham, UK, pp. 91-105.

Danoucaras, A.N., Woodley, A., Vink, S., 2013. Corporate sustainability reporting for water: Water Footprint, Global Reporting Initiative and the Water Accounting Framework, 6th International Conference on Sustainable Development in the Minerals Industry, Milos Island, Greece.

Fonseca, A., McAllister, M.L., Fitzpatrick, P., 2013. Measuring what? A comparative anatomy of five mining sustainability frameworks. Minerals Engineering 46–47, 180-186.

GEMI See: Global Environmental Management Initiative, 2010. Water Sustainability Tool. Available at: http://www.gemi.org/water/overview.htm (accessed 13.08.2010).

GRI See: Global Reporting Initiative, 2013. G4 Sustainability Reporting Guidelines Implementation Manual. Global Reporting Initiative, Amsterdam. Available at: https://www.globalreporting.org/resourcelibrary/GRIG4-Part2-Implementation-Manual.pdf (accessed 15.10.2013).

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., Mekonnen, M.M., 2011. The Water Footprint Assessment Manual. Water Footprint Network, London, p. 203.

Leong, S., Hazelton, J., Taplin, R., Timms, W., Laurence, D. Mine site-level water reporting in the Macquarie and Lachlan catchments: a study of voluntary and mandatory disclosures and their value for community decision-making. Journal of Cleaner Production (2014), http://dx.doi.org/10.1016/j.jclepro.2014.01.021

MCA See: Minerals Council of Australia, 2014. Water Accounting Framework for the Minerals Industry User Guide Version 1.3 - January 2014, in: MCA (Ed.). Available at: http://www.minerals.org.au/focus/sustainable_development/water_accounting (accessed 29.05.2014).

MCA See: Minerals Council of Australia, 2013. MCA Member Companies. Minerals Council of Australia. Available at: http://www.minerals.org.au/corporate/mca_member_companies (accessed 09.12.2013)

Molden, D., Sakthivadivel, R., 1999. Water accounting to assess use and productivity of water. International Journal of Water Resources Development 15, 55-71.

Morrison, J., Schulte, P., 2010. Corporate Water Accounting, in: United Nations Environment Programme, United Nations Gobal Compact, Pacific Institute (Eds.). Pacific Institute, Oakland, California, USA.

Mudd, G.M., 2008. Sustainability reporting and water resources: A preliminary assessment of embodied water and sustainable mining. Mine Water and the Environment 27, 136-144.

Osman, A., Crundwell, F.C., Harding, K.G., Sheridan, C.M., du Toit, A., 2013. Water accountability and efficiency at a base metals refinery, in: AusIMM (Ed.), AusIMM Water in Mining 2013 conference. AusIMM, Brisbane, Queensland, pp. 277-286.

WASB See: Water Accounting Standards Board, 2012. Australian Water Accounting Standard 1: Preparation and Presentation of General Purpose Water Accounting Reports. Commonwealth of Australia, Canberra. Available at: http://www.bom.gov.au/water/standards/wasb/wasbawas.shtml (accessed 28.11.2012).

Woodley, A.P., Danoucaras, A.N., Mccombe, C., Kunz, N.C., Collins, N., 2013. A Robust Methodological Approach for Mine Site Water Accounting, Water in Mining 2013 conference. AusIMM, Brisbane, Queensland, pp. 335-341.

Highlights (for review)

The Water Accounting Framework was applied to four commodities in three countries.

We found reporting statements of the framework could be generated for each site.

The reports highlighted the advantages of the method of the Water Accounting Framework.

This demonstrated the flexibility of the framework within the standardization.

Figure 1: Conceptual model

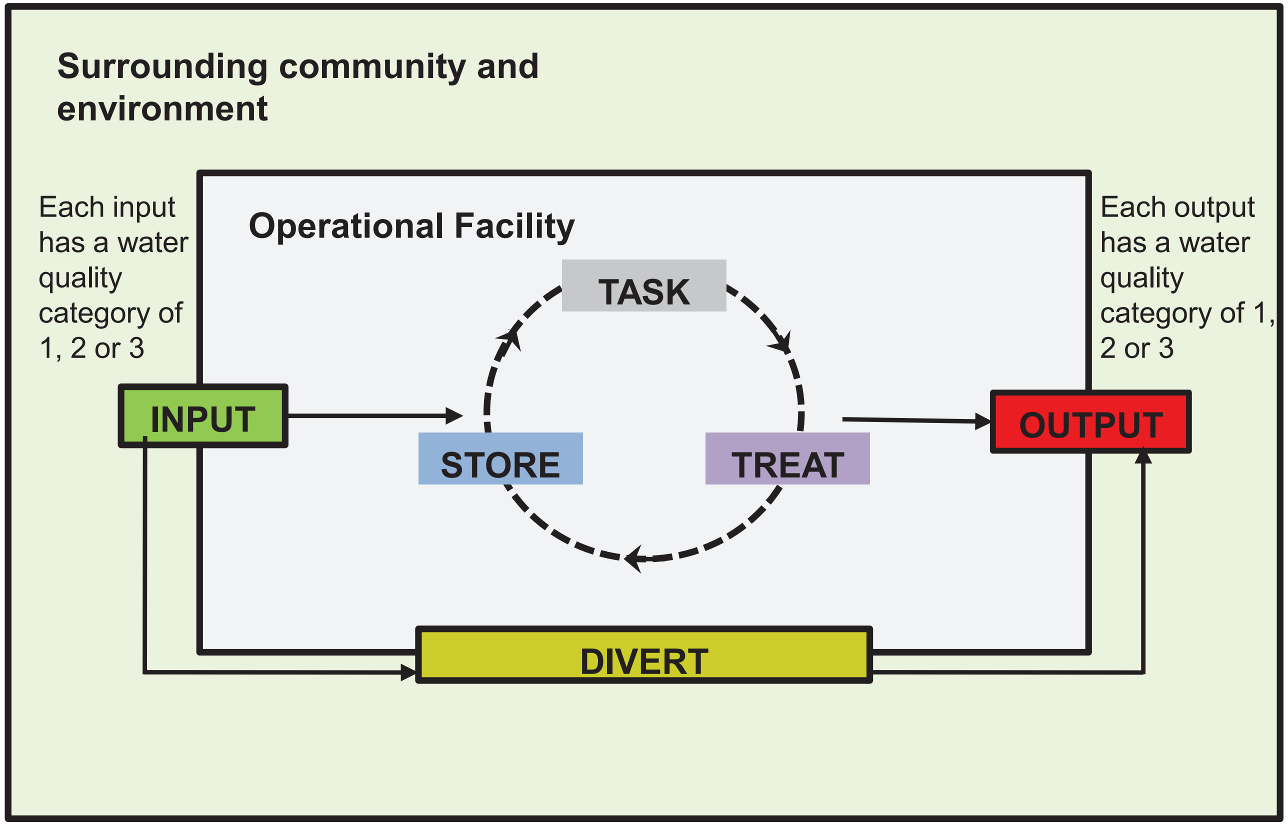

Figure 2: decision tree

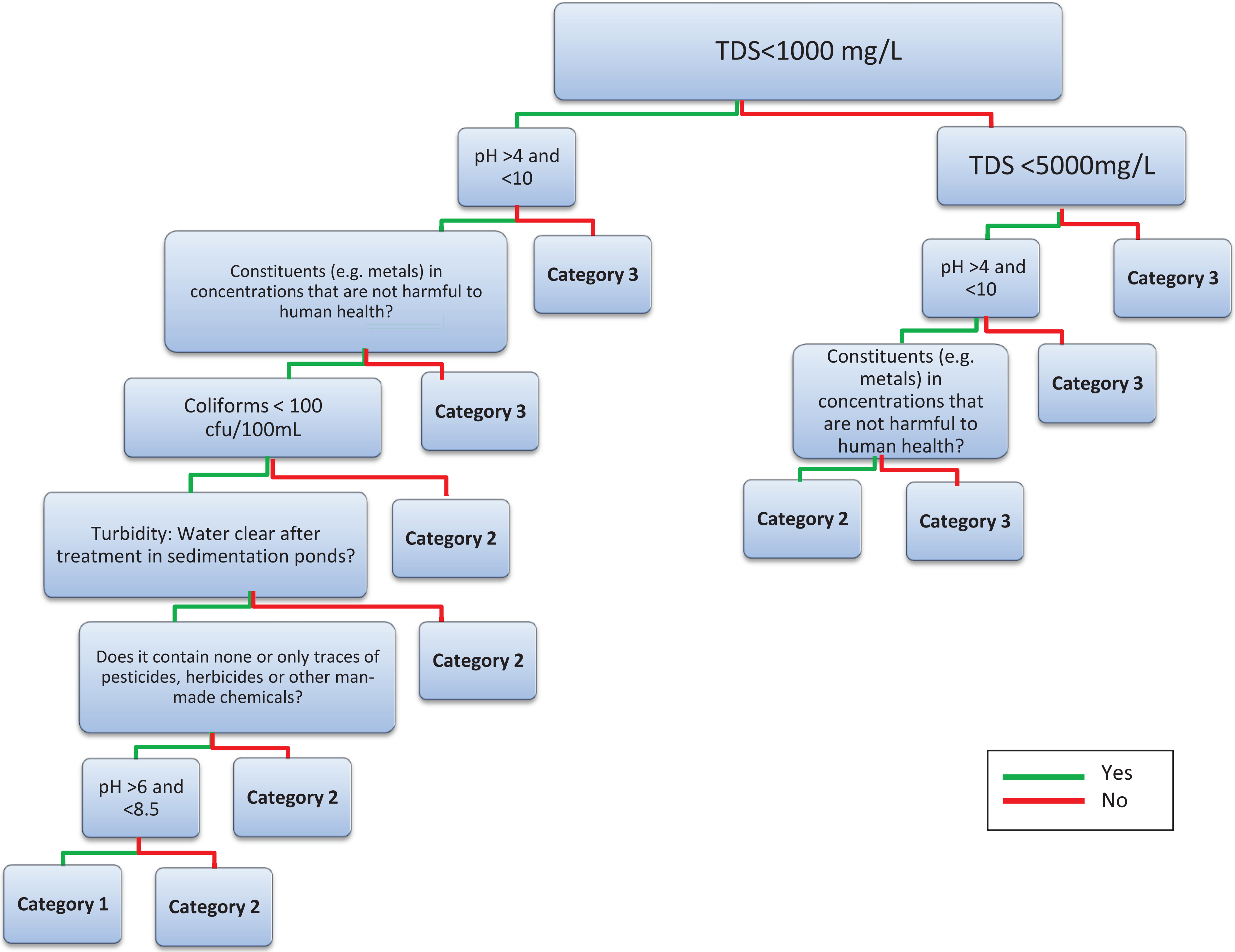

Table 1

Source	Definition	Input
Surface Water	All water naturally open to the atmosphere, except for water from oceans, seas and estuaries	Precipitation and Runoff
		Rivers and Creeks
		External Surface Water Storages
Groundwater	Water beneath the earth's surface that fills pores or cracks between porous media such as soil, rock, coal, and sand, often forming aquifers. For accounting purposes, water that is entrained in the ore can be considered as groundwater	Dewatering of ore body
		Bore Fields
		Ore Entrainment
Sea Water	Water from oceans, seas and estuaries	Estuary
		Sea/Ocean
Third Party	Water supplied by an entity external to the operational facility. Third-party water contains water from the other three sources. When the source is known, the physical source (surface water, groundwater, sea water) should prevail.	Contract/Municipal
		Waste Water of another user

Table 2

Destination	Definition	Output
Surface Water	All water naturally open to the atmosphere, except for water from oceans, seas and estuaries	Discharge
		Environmental Flows
Groundwater	Water beneath the earth's surface that fills pores or cracks between porous media such as soil, rock, coal, and sand, often forming aquifers.	Seepage
		Aquifer reinjection
Sea Water	Water to oceans, seas and estuaries	Estuary
		Sea/Ocean
Third Party	Water supplied to an entity external to the operational facility.	Third Party
Other	Includes evaporation, entrainment, task loss and any other destination that is not covered by the other pathways.	Evaporation
		Entrained water in waste material (tailings, coarse rejects) and product
		Task loss

Table 3

Source	Site 1 - coal Aus			Site 2 -iron Aus	Site 3- copper South America		Site 4 - platinum Africa	
	1 (ML)	**2 (ML)**	**3 (ML)**	**1 (ML)**	**1 (ML)**	**2 (ML)**	**1 (ML)**	**2 (ML)**
Surface Water	4682	1700	0	0	685	0	1211	0
Groundwater	0	350	602	10324	0	149	1033	1347
Seawater	0	0	0	0	0	0	0	0
Third party	0	0	0	0	1326	0	0	4750
Unknown flow	0	0	0	0	36	0	0	1262
Input per water quality category	**4682**	**2050**	**602**	**10324**	**2047**	**149**	**2244**	**7360**
Input per site	**7334**			**10324**	**2196**		**9604**	
Destination	**1 (ML)**	**2 (ML)**	**3 (ML)**	**1 (ML)**	**1 (ML)**	**2 (ML)**	**1 (ML)**	**2 (ML)**
Surface	0	0	0	3654	82	0	3	0
Groundwater	0	810	0	0	0	0	0	240
Seawater	0	0	0	0	0	0	0	0
Third party	0	0	0	0	0	0	0	6
Other	6900	84	1413	6670	1238	876	3711	1912
Output per water quality category	**6900**	**894**	**1413**	**10324**	**1320**	**876**	**3714**	**2158**
Output per site	**9207**			**10324**	**2196**		**5872**	
Storage at start (ML)	**15,773**						**Unknown**	
Storage at end (ML)	**13,900**						**Unknown**	
Change of Storage (ML)	**-1873**			**0**	**0**		**3732**	

Diversions

	Site 1			Site 2
Source	**1 (ML)**	**2 (ML)**	**3 (ML)**	**1 (ML)**
Surface Water	281	171	0	unknown
Input per site	**452**			
Destination	**1 (ML)**	**2 (ML)**	**3 (ML)**	**1 (ML)**
Other	452	0	0	unknown
Output per site	**452**			

Table 4

	Site 1	Site 2	Site 3	Site 4
Total volume to tasks (ML/year)	5741	6670	5579	29,715
Total volume of reused water (ML/year)	2000	0	3588	20,177
Reuse efficiency (%)	35	0	64	68
Total volume of recycled water (ML/year)	0	0	0	0
Recycling efficiency (%)	0	0	0	0

Table 5

Source	Input	Water Quality Categories		
		1 (ML)	2 (ML)	3 (ML)
Surface Water	*Precipitation and Runoff*	4392	1700	
	Rivers and Creeks	290		
Groundwater	*Aquifer Interception*		350	
	Entrainment			602
TOTAL INPUTS: 7334ML		**4682**	**2050**	**602**
Destination	**Output**	**1 (ML)**	**2 (ML)**	**3 (ML)**
Groundwater	*Seepage*		810	
Other	*Evaporation*	6900		
	Entrainment			1413
	Other - task loss		84	
TOTAL OUTPUTS: 9207ML		**6900**	**894**	**1413**

Diversions

Surface Water	*Precipitation and Runoff*	281	171	
TOTAL DIVERSION INPUTS: 452ML		**281**	**171**	**0**
Other	*Evaporation*	452		
TOTAL DIVERSION OUTPUTS: 452 ML		**452**		**0**

Table 6

Source	Input	Water Quality Categories		
		1 (ML)	2 (ML)	3 (ML)
Groundwater	*Dewatering Bore Fields*	10244		
	Supply Bore Fields	80		
TOTAL INPUTS: 10,324 ML		**10324**	**0**	**0**
Destination	**Output**	**1 (ML)**	**2 (ML)**	**3 (ML)**
Surface Water	*Discharge*	3654		
Other	*Evaporation*	2768		
	Task losses	3902		
TOTAL OUTPUTS: 10,324 ML		**10324**	**0**	**0**

Diversions

Surface Water	*Precipitation and Runoff*	Unknown		
TOTAL DIVERSION INPUTS:				
Other	*Evaporation*	Unknown		
TOTAL DIVERSION OUTPUTS:				

Table 7

		Water Quality Categories		
Source	**Input**	**1 (ML)**	**2 (ML)**	**3 (ML)**
Surface Water	*Rivers and Creeks*	685		
Groundwater	*Entrainment*		149	
Third Party Water	*Contract/Municipal*	1169		
	Waste Water	157		
	Unknown	36		
TOTAL INPUTS: 2196 ML		**2047**	**149**	
Destination	**Outputs**	**1 (ML)**	**2 (ML)**	**3 (ML)**
Surface Water	*Discharge*	82		
Other	*Evaporation-from stores and TSF*	73		
	Evaporation from road	746		
	Evaporation from product & waste	419		
	Entrainment		793	
	Task loss		83	
TOTAL OUTPUTS: 2196 ML		**1320**	**876**	