Centre for Water in the Minerals Industry
Sustainable Minerals Institute
University of Queensland
Brisbane 4072
Australia
Purpose: ***To facilitate the capture of benefits from opportunities associated with sustainable water management in the minerals industry***

Water Issues and Sustainable Resource Processing

Centre for Sustainable Resource Processing

Document reference: 05-003-068.doc
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First Edited: 17 January 2007
Last edited: 17 April 2007

Executive Summary

The paper was written in response to objectives set by CSRP:

- Provide an overview of the 'state of play' and key trends in water management in the area of resource processing.
- Identify significant challenges and constraints facing the industry.
- Highlight examples of good practice and innovation.
- Define the key issues facing industry from a sustainability perspective.
- Identify significant knowledge gaps and priority areas for research.

Chapter 2 provides an overview of water use in Australia, focussing on water use within the minerals industry. Analysis of sustainability frameworks and corporate sustainable development reports (Chapter 3) indicate that there is no consistent approach being adopted for frameworks, and that targets for water management are highly variable. There is a tendency to report water use-production ratios, but these are highly variable and offer little insight into how well water is being managed. Similarly, economic production ratios ($/Ml) provide little insight because they overlook the different cost structures within the businesses.

A hierarchical conceptual systems approach was developed for analysis of water management to help identify the actions that would lead to improvements. The model has five levels (Chapter 4).

Level 1 represents the **unit operations** performing the steps in the mineral processing sequence (grinding, leaching, flotation and dewatering). The major issues identified at this level are that there is a lack of knowledge about the interactions between water quality and performance of unit operations, and that the relationship between water and energy use is not included as design priority.

Level 2 represents the combining of unit operations to form a process chain, with the focus being on **the interactions between unit operations** - water, reagent and energy fluxes. The main issue is a lack of supporting tools for quantifying the differences in water, reagents and energy uses between one set of linked unit operations and another.

Level 3 constitutes a system representation of the whole site or operation, with the focus being on **interactions between major site processes**. The main issues are:

- site water management is confined to operational 'silos';
- the switch to using more site water, with increasing reuse, results in sensitivity to climate variation; and,

- the conditions that must be met for acceptable closure of operations are becoming increasingly stringent.

Level 4 represents the site **as a single unit,** with water, energy and reagents as overall inputs and outputs of the site. The main issues are*:*
- government and company policy requirements;
- influences on the operating conditions from the surrounding community and environment;
- knowledge and data management; and,
- comparison between operations.

Level 5 is concerned with **linked sites.** Examples exist where geographic proximity facilitates synergies, such as the Kwinana Industrial Area in Western Australia, where processing industries are closely integrated so that the products of one process provide raw materials to a downstream operation. Sites can also be linked via non physical concepts such as product stewardship or corporate sustainability goals.

Chapter 5 addresses challenges with using sustainability to meet operational needs. The integrative nature of sustainability is proposed as a mechanism to bring together the multiple demands on operations.

Based on the issues that have arisen from the analysis, the following research responses are suggested. At the basic level of describing water use and associated systems, there does not appear to be a summary of water infrastructure associated with resource processing; CSRP could consider producing one. With respect to water management at each level, suggested research projects are to:

Level 1) Develop a catalogue of unit operation options for water use, chemical conditions and interactions with minerals, improved synergies and constraints to efficiency, and energy consumption and efficiency. This could be developed as an on-line tool provided by CSRP as an industry service.

Level 2) Develop a tool or information database for quantifying the differences in water, reagents and energy uses between one set of linked unit operations and another, enabling the estimation of overall system performance in terms of expected output, (e.g. mineral recovery or commodity purity level), operating and maintenance impacts on profitability and contribution towards sustainability objectives.

Level 3) Determine whether managing water in an integrated manner results in improved management and, if not, propose additional process improvement; develop better system management of recycling and reuse; provide practical information on strategic site water planning to assist with achieving desirable endpoints after mining.

Level 4) Develop integrated systems that provide sites with all information impacting on water management strategies, from technical aspects to policy requirements and influences on the operating conditions from the surrounding community and environment. Systems models that allow valid comparisons between sites – as a vehicle to improve overall water performance – are needed.

Level 5) Quantify the benefits of linked sites, and attempt to understand the limits imposed by reporting benefits that accrue to one company from another's actions. When the manufacture of a product requires involvement of several operations, reducing water use in one operation can increase the water use in another operation. An example would be an increase in the use of salty water requiring more fresh water imports in downstream operations. Therefore, it can be difficult to identify and credit the process responsible for changes in water management performance.

In addition to the central issues outlined above, issues arising from industry participation in the project were tabulated (Appendix C). These individual issues and suggested research responses range from the process-specific to the very general. These tables provide a receptacle for addition of issues that have not been raised or captured in this initial process. CSRP could develop an on-line capability for industry to browse and add to the water issues. This would create a 'living' repository of information on industry water issues. A research agenda for CSRP could be compiled by selecting from these lists and investing in line with industry-derived prioritisation of the issues raised.

A significant opportunity for CSRP emerges. It is to design, implement and test tools that will link operational/technical performance imperatives for water management to sustainability objectives. This would include consideration of energy needs/efficiency and chemical interactions. No such integrated tool exists. Development by CSRP, with industry support, will demonstrate a logical and powerful approach to industry leadership. It will deliver a novel reporting capability which integrates the linkages inherent in sustainability thinking. An example of one suitable conceptual model upon which this could be based is presented in this paper. Such a tool could be designed to be developed in modular fashion, producing a commercial output from CSRP that could grow over time.

The supporting full documentation to this paper can be found at:

Water Issues Paper –CSRP Report XXX (CWiMI reference 05-003-057.doc)
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Table of Contents

Chapter 1 - Background

This paper was written in response to objectives set by the Executive and Board of the Cooperative Research Centre for Sustainable Resource Processing (CSRP). The objectives were to:

- Provide an overview of the 'state of play' and key trends in water management in the area of resource processing.
- Identify significant challenges and constraints facing the industry.
- highlight examples of good practice and innovation.
- Define the key sustainability issues facing industry.
- Identify significant knowledge gaps and priority areas for research.

The commodities that were studied as part of this project were alumina, steel, gold, coal, mineral sands and uranium. The information that underpins the paper was compiled using one-on-one interviews with key industry contacts, site visits to Gladstone and Kwinana, library and on-line structured searching of public information and a two-day Industry Roundtable.

Chapter 2 reviews current minerals industry water consumption and associated water supply systems, and highlights the absence of a consistent framework for reporting water use. Chapter 3 explores the link between performance in water management and ability to abide by sustainable development principles. It concludes that companies that excel in implementing sustainable development principles tend to be the best water managers. However, it is often the most readily achievable water management goals that have been reached and it is argued that further progress could be made.

It is concluded that industry could improve its water management strategies, and that there are several levels at which this could occur, from specific technical improvements for a particular process (e.g. address the impact of water quality on flotation processes to increase water recycling) to increasing linkages between site operations and responding to community pressures. To report on the various water issues that the industry is facing, an organising framework, based on the building blocks of mineral processing operations, from unit operations to linked sites (regional synergies) is proposed. Issues and research responses can be derived at each level of the organising framework (Chapter 4).

Chapter 5 draws out the tension between water management for production and water issues associated with sustainability. The proposed framework is presented as a means for dealing with this tension in a structured and strategic manner. Some examples are provided. The section concludes with a set of issues and research responses for the interface of sustainability and operational water management.

Chapter 2 - An Overview of Water and the Minerals Industry in Australia

2.1 Overall Water Use

The minerals industry needs water for human consumption; the transport of ore and waste (slurries, suspension); minerals separation; physical separation of material (jetting); cooling (power generation); dust suppression (during crushing/screening, for conveyors and roads), and washing equipment. It also needs to manage the dewatering of mines.

The industry accounts for only 2-3% of Australia's water use. However, mineral, mining and manufacturing operations are commonly based in remote locations, where the operations may require a significant proportion of the water available to the community. The context in which a company is operating is, therefore, crucial to understanding water issues.

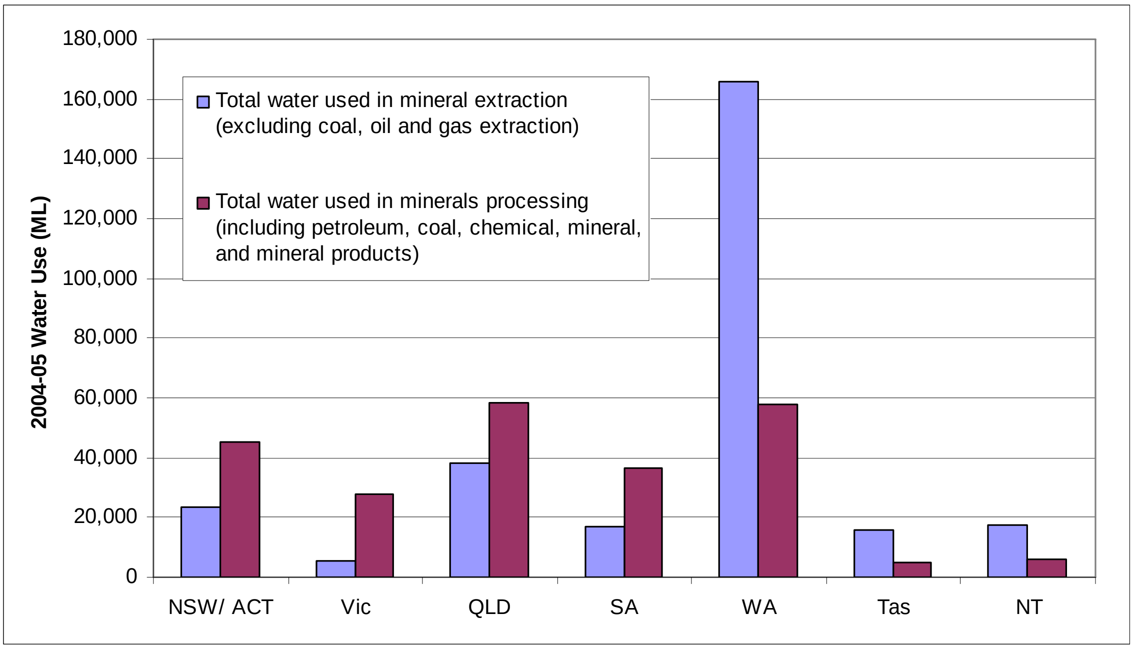

Figure 1. Distribution of water use by State for mining and minerals processing. Source: Australian Bureau of Statistics (2006).

The Australian Water Account (Australian Bureau of Statistics 2006) provides an estimate of water use by state for various mining and minerals processing operations, which is summarised in Figure 1. The maroon columns display water consumed by mining extraction (excluding coal, oil and gas extractions) and the blue columns display water consumed by the processing of petroleum, coal, chemical and associated products, non-metallic minerals products and metal products. Unsurprisingly, the states with the highest levels of mineral extraction and processing, Western Australia and Queensland, use the most water.

2.2 *Water Supply*

The Australian mineral extraction industry supplies more than 90% of its water needs through its own infrastructure. In contrast, the mineral processing industry relies primarily on mains water for supply, rather than self extraction (Figure 2). The implications of this are that processing operations are more reliant than mines on the infrastructure used to deliver water to the surrounding communities, and on the water source itself.

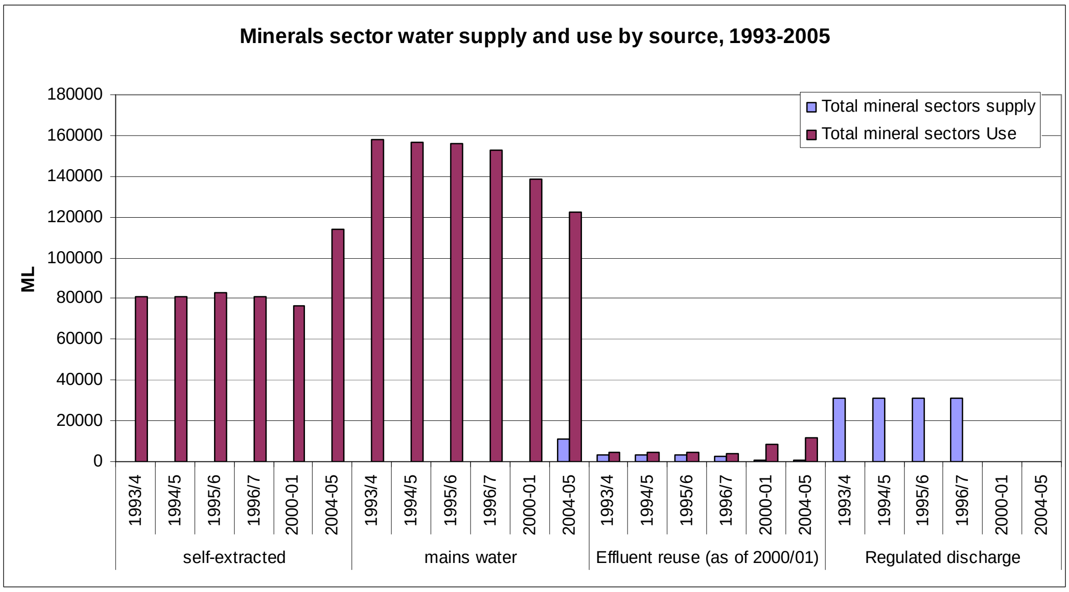

Figure 2 - Minerals sector water supply and use by source, 1993-2005. Source: Australian Bureau of Statistics (2006).

Figure 2 also demonstrates that the mineral processing industry has taken steps to reduce its reliance on mains infrastructure and reduced overall water consumption over the last six years of reporting.

2.3 *Water Systems and Infrastructure*

No summary was found describing all of the infrastructure provided and operated to deliver water to mining and minerals processing. However, there is clear evidence of a large amount of infrastructure existing and being planned. An industry statement delivered through the Minerals Council of Australia (2004) on national water reform argues that Australian minerals operations install, operate and maintain some of the infrastructure necessary for their water supply. Related costs are borne by industry and in many circumstances the infrastructure provided and maintained by industry is shared with other stakeholders in the region, including neighbouring communities, farmers and pastoralists.

In Western Australia, the minerals industry supplies 95% of its own water needs (Economics Consulting Services, 2004), with groundwater being the most common source. Western Australia and the Northern Territory are the only two Australian states whose mining and minerals operations utilise more groundwater than surface water (Economics Consulting Services, 2004).

Queensland relies on surface water, which represents a major challenge as Queensland has the most variable climate in the world (Claydon, 2003). The major minerals processing industries within Queensland are located in the Gladstone region, with Awoonga Dam currently supplying the majority of water. The state government has a progressive policy towards further industrial development of Gladstone, the success of which will depend the adequacy of potential additional supplies from the Fitzroy River Barrage (Department of Natural Resources and Mines, 2005).

2.4 Water Quantity

Based on some case studies, an attempt was made to compile the water volumes that were required to produce the commodities of interest (alumina, steel, gold, coal, mineral sands and uranium). This review highlights the variety of water consumption indicators that were reported, when any were reported at all (Table 1). Reporting on water consumption is not consistent across the industry with respect to the level at which it occurs (the whole process or a particular unit operation within a process), the quality of the water that is being consumed (fresh or recycled), and the units that are used.

Table 1 – Example of water requirement for commodity production

Commodity	Source	Water Consumption Indicator
Alumina	QAL alumina refinery (Stegink, 2003)	1647 m3/hr raw water
Steel	Port Kembla SteelWorks (Hird, 2006)	2.6kL fresh water/tonne
Gold	(La Brooy and Muir, 1994)	7-19 m3/hr for elution
Coal	Centre for Water in the Minerals Industry (2006)	1116 ML/Mt pa total demand (average across a number of mines)
Mineral Sands	Mining operation at North Stradbroke Island	50ML/day
Uranium	n/a	n/a

An alternative approach to deriving typical water consumption figures is to calculate the embodied water for various metal production processes. Embodied water refers to the volume of water that is used from the point of extraction to the point of secondary manufacturing. Norgate and Lovel (2006) apply this approach to calculate water consumption figures as summarised in

Table 2. This study showed that indirect water consumption, in particular for electricity generation, can make a significant contribution to the embodied water value (for aluminium production).

These calculations are useful for comparing the relative water consumption of different production processes for the same metal (e.g. production of lead using a blast furnace or using the imperial smelting process). Moran (2006) warns that such data should be interpreted with caution. Some of the issues include:

- The embodied water is often used to derive economic value per m^3 of water but these economic calculations are based on the gross value of production rather than profit, and can misrepresent the market value of the commodity.
- As the calculations include indirect water consumption, the variations are often related to differences in power consumption rather than differences in processing methods;.
- Dramatic short-term improvements in water consumption per tonne may often be attributed to the indirect effects of technology changes, rather than direct efforts to reduce water consumption.
- The data neglect the fact that water does not 'disappear' once it is used within a mine site; some proportion is recycled to other water users (e.g. treatment in a waste water treatment facility and eventual discharge to groundwater). This issue is also discussed in depth by Younger (2006).

2.5 Water Quality

The management of water in minerals operations may be dictated by water quality issues. The processes that are used may have significant impacts on water quality, and/or may depend on specific quality requirements that are not always met by available water sources (e.g. self-extracted groundwater of variable quality). This means that alternative sources may need to be sought which may be more expensive and/or create more competition with other potential users. Similarly, treating water so it is fit for purpose may be expensive and incur undesirable additional energy use.

Table 2 - Embodied water consumption for metal production by various processes. Adapted from Norgate and Lovel (2006).

Metal	Process	Water consumption	
		m3 water/t metal	*m3 water/t ore*
Copper	Copper - Smelting/converting and electro-refining	25.9	0.7
Copper	Copper - Heap acid leaching and SX/EW	38	0.5
Nickel	Nickel - Flash furnace smelting and Sherritt-Gordon refining	79	1.4
Nickel	Nickel - Pressure acid leaching and SX/EW	376.6	3.5
Lead	Lead - Blast furnace	12.6	0.5
Lead	Lead - Imperial smelting process	21.7	0.9
Zinc	Zinc - Imperial smelting process	21.2	1.5
Zinc	Zinc - Electrolytic process	26.3	1.8
Aluminium	Aluminium - Bayer/Hall-Heroult processes	35.9	6.2
Titanium	Titanium - Becher/Kroll processes	110	5.4
Iron/steel	Iron/steel - Blast furnace and basic oxygen furnace	2.9	1.8
Stainless steel	Stainless Steel - Electric arc furnace/argon oxygen decarburisation - ferronickel feedstock	74	13.7
Stainless steel	Stainless Steel - Electric arc furnace/argon oxygen decarburisation - nickel feedstock	13.4	2
Gold	Gold - CIL cyanidation and EW/smelt	252087	0.8

Chapter 3 - Sustainability Frameworks and Reporting

3.1 Sustainability and its relationship to water

Given the important role of water management in meeting environmental standards and community expectations, the development of approaches to sustainability in resource processing are central to understanding water issues in the industry. Water is one component of resource processing business operations that is involved in all aspects of business and sustainability reporting. This means that water may be an excellent test of the robustness and general applicability of sustainability principles and their implementation guidelines.

Therefore, this paper reviews sustainability frameworks and makes an assessment of how well minerals companies are progressing in sustainability as evidenced through their annual sustainability reports. Given the position stated above on water, an attempt has also been made to assess progress on water within sustainable development reporting.

3.2 Sustainability Frameworks

No other industry can claim to have expended more effort nor reached greater consensus on sustainability principles than the minerals industry. The minerals industry founded its sustainability principles through an extensive global process known as *The Mining, Minerals and Sustainable Development Project* (MMSD, 2002), which provide an in-depth analysis of global trends and summarises a set of sustainable development principles for application at the global level. The International Council on Mining and Minerals (ICMM) was formed to take the MMSD agenda forward (International Council on Mining and Minerals, 2003). ICMM developed a framework consisting of ten 'Sustainable Development Framework Principles' and provided guidelines for their implementation. Table 3 places this framework in context of scale of applicability (global to local) and ownership (company, sector, generic) with a number of other frameworks.

Most companies have a specific statement regarding sustainability frameworks. However, there is a lack of consistency of content which derives from a lack of agreement over what constitutes a framework for sustainability. Table 4 summarises a possible content definition for a sustainability framework.

Table 3 - Sustainability Frameworks organised into a matrix indicating scale of applicability and scope of ownership.

Global	• Rio Tinto • BHP Billiton	• ICMM Framework • Framework for Responsible Mining	• Natural step • Ecological Footprint • SIGMA	• World Business Council Water Strategy
National		• Enduring Value • Resilience Model (coal)	• Australian National Strategy for ESD	• Water Framework Directive • National Water Initiative
Location		• Innovation and Technology Sustainability Performance Management Framework (ITSPM)	• CQ Strategy for Sustainability	• Strategy for Water Management at Mine Sites (Minerals Council of Australia and NWI)
	Company	**Sector**	**Generic**	**Water**

Table 4 – A proposed set of components for a sustainability framework

Component	Description
Ecological values	A description of how the framework conceptualises the ecological system, human-nature interactions, and the relationship of ecosystems to human decision making (Hodge, 1997).
Definition of sustainability	An indication of the ideological position on the meaning of sustainability; including basic assumptions about how it is best achieved.
Principles of sustainable development	A set of statements or policy goals relating to sustainable development.
System	Define the system(s) to which the framework will be applied. This entails defining the system components and their interactions. In particular, sustainability initiatives must be linked directly to the corporate business systems to achieve the necessary integration.
Indicators	Measures for system components and their interactions that will be used to assess progress on achieving the principles.
Strategy	An indication of how the sustainability principles are implemented, including: ➢ specific roles of all actors (from the CEO to the plant operator) ➢ targets ➢ corporate structure and processes ➢ tools, e.g. economic instruments, environmental management systems, cost-benefit analysis, quality assurance, stakeholder analysis, eco-efficiency, taxes

Outcomes	Reporting on the benefits and dis-benefits to the company of their performance in meeting the targets. These will be a direct consequence of the decisions made to formulate and implement the strategy.

3.3 Sustainability Reporting

Corporate sustainability reports are publicly available reports which provide a means for companies to increase transparency and accountability in relation to sustainability (Department of Environment and Heritage, 2006). The reports are commonly published as a stand-alone document, but may also be integrated into a company's annual report. Sustainability reporting has been formalised by requirements of the Global Reporting Initiative (GRI), which provides a suggested list of contents for corporate sustainability reports. The GRI Mining and Minerals Supplement outlines sixteen core indicators and nineteen additional indicators for environmental performance (Global Reporting Initiative, 2005). As summarised in Table 5, six of these indicators relate to water. A more detailed description of the GRI water indicators is provided in Appendix A.

Table 5 - GRI indicators relating to water

GRI indicator	Description
EN05	Total water use (compulsory).
EN12	Significant discharges to water.
EN20	Water sources and ecosystems affected by water use.
EN21	Annual withdrawals of ground and surface water (% of annual renewable quantity of water available).
EN22	Total recycling and re-use of water.
EN32	Water sources and ecosystems affected by discharges of water and run-off.

The sustainability reports for twenty-seven minerals companies were reviewed. A systematic analysis was conducted by rating each report in terms of sustainability and water management performance. Whilst similar analyses have been conducted by international consultants such as the Roberts Environmental Centre (Morhardt *et al*, 2006), they have not compared progress towards sustainability with progress in water management.

Figure 3 encapsulates our results. The data points represent the water and sustainability scores obtained through application of our analysis criteria (summarised in Appendix B). The blue line is the regression line that can best describe the data points ($R^2 = 0.65$). The black line provides a reference slope of 1. Data points located above the black line represent companies for whom the water score was better than sustainability score. Similarly, data points located under the black line represent companies for whom the sustainability score was better than water score.

Companies that excel in abiding by sustainability principles tend be the best water managers: they are represented by the data points located in the upper right-hand corner of the graph. Companies that do not score well for sustainability tend to score better for water (above the black line). This is a result of conventional management of water as a utility being relatively easily translated into sustainability terms. However, once these readily achievable water management goals have been reached, the rate of progress in sustainability score is not matched with a commensurate progress in dealing with water issues. This is demonstrated in the slope of the regression line being less than 1 – the sustainability scores tend to increase faster than the water scores.

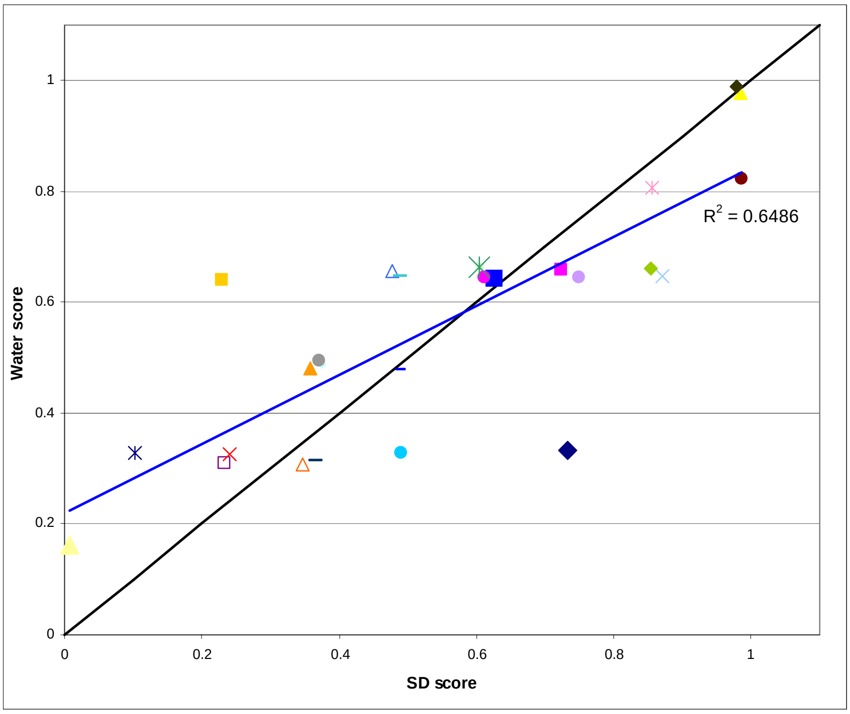

Figure 3. Results from a semi-quantitative analysis of the quality of minerals industry SD reporting and the representation of water in those reports.

This analysis should be seen as broadly indicative only because a wide range of companies (and some subsidiaries) are represented. Therefore, the calculated scores are unlikely to be strictly comparable.

3.4 Conclusions

The conclusions that can be drawn from the review of overall water use are that:

- The minerals industry needs reliable water supply as it cannot operate without it. It obtains its water from a range of sources, and directly or indirectly impacts on natural sources of water (surface and groundwater). Given the current water supply constraints witnessed in Australia, the industry has an excellent opportunity to place itself as a leader in water management.

- The main constraints placed on potential water savings initiatives are related to water quality and energy requirements.

- Water use is currently reported in an anecdotal manner, with no agreed system for organising the information.

- Water management should be clearly beyond broad GRI indicators integrated in each company's policy on sustainable development.

The next chapter deals with the framework that is proposed to help describe, categorise and address water issues in the minerals industry.

Chapter 4 - Summary of Water Issues and Research Responses

4.1 Organising Framework: a Hierarchical Conceptual Systems Model

The proposed organising framework has the following key features:

- It is based on the building blocks of mineral processing operations, from the smallest (unit operations) to the largest (linked sites). It is a hierarchical framework.
- It remains a suggestion, and could easily be modified to suit specific constraints. At this stage, the framework is only conceptual.
- Within each building block, the aim is to describe the essence of the water system without describing all details. The framework is aligned with the philosophy of a systems model.

Our approach is thus termed a hierarchical conceptual systems model and has five levels: unit operations, processing plant, site water tasks, site, and linked sites (as outlined in Figure 4).

4.2 Level 1 – Unit Operations

Level 1 represents the unit operations concerned with the basic steps in the mineral processing sequence, e.g. grinding, leaching, flotation and dewatering.

At this level, a typical water management strategy is internal recycling: water is recovered and is reused within the same single unit operation.

Grinding

Grinding circuits usually use water as it provides five key benefits:

- lower power consumption per tonne of product
- higher capacity per unit of mill volume
- ability to use wet screening for product control
- elimination of dust problems
- enables the use of simple transport methods such as pumps and pipes.

Examples of water and energy consumptions are summarised below:

Table 6 – Indicative water and energy consumption figures for grinding circuits (Corder, 2006)

Unit Operation	Typical Water Use	Typical Energy Use
Crushing	None	~ 0.1 to 10 kWh/t ore
Grinding (with cyclone classification – up to cut size of ~300 microns)	~1 to ~3 t water/t ore[1]	~8 to ~30 kWh/t ore[2]
Grinding (with screen classification – above a cut size of ~300 microns)	~0.33 to ~1 t water/t ore [3]	

Note: The water data in this table refers to process water usage and does not include auxiliary water usage such as that used for cooling motors that run equipment.

With grinding, water management strategies would focus on internal recycling (water is recovered and is reused within the same single unit operation) and technological advances that could reduce or eliminate water use (e.g. microwave grinding). The main issue raised was that the changes in water quality brought about by internal recycling could impact on grinding and subsequent downstream unit operation, and that these potential impacts need to be better understood.

[1] ~25% to 50% wt solids/total slurry wt in cyclone overflow stream

[2] Depends on hardness of ore

[3] ~50% to 75% wt solids/total slurry wt in screen or sieve bend undersize

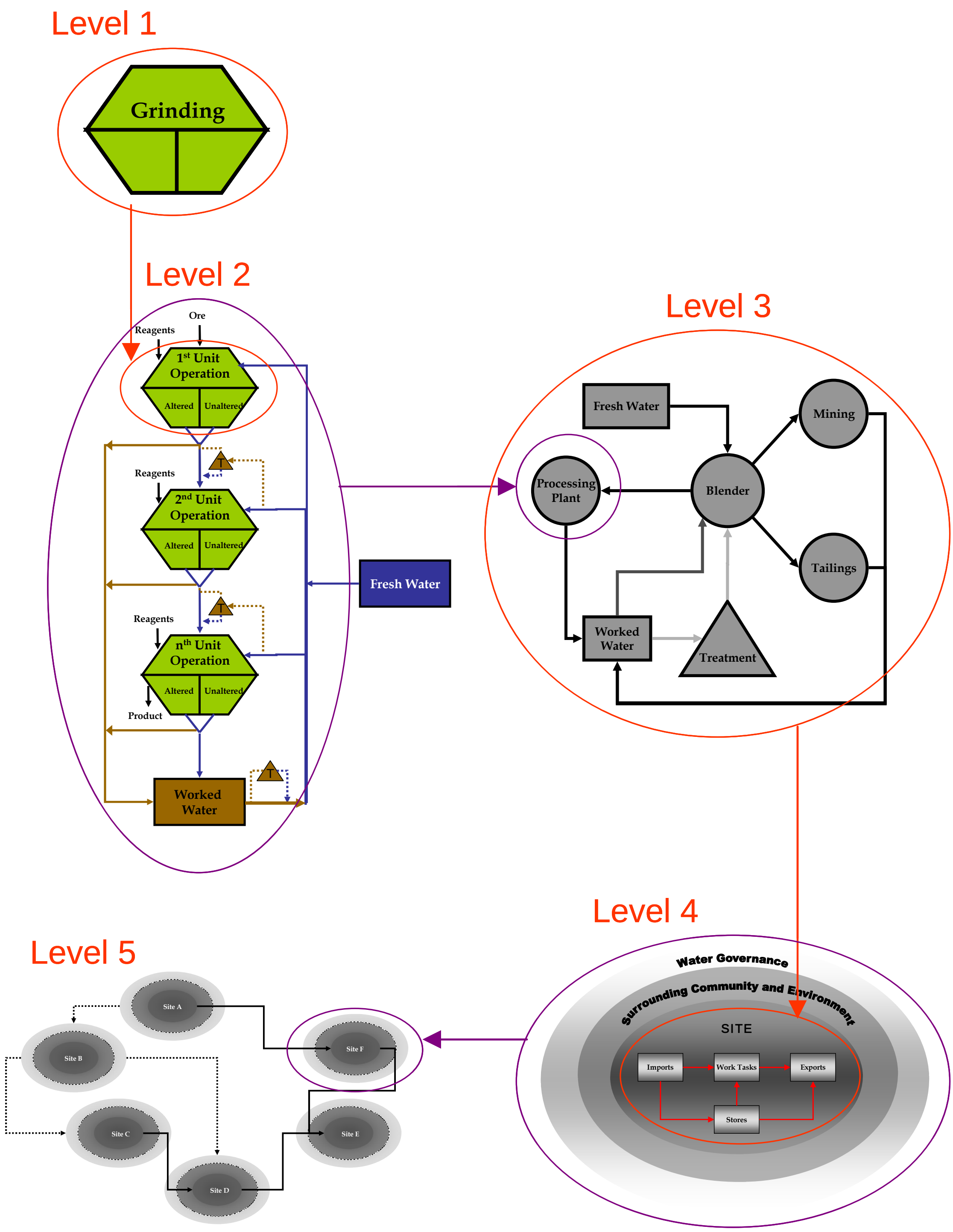

Figure 4- Hierarchical Conceptual Systems Model

Leaching

Leaching uses wet analytical chemistry to separate mineral from unwanted gangue material. Various types of leaching techniques are used in industry, depending on the nature of the ore to be processed. All involve mixing water with reagents, with some reagents being toxic, raising specific environmental issues (e.g. cyanide solution recovered from heap leaching operations and stored in ponds, which could kill wildlife in the surrounding area if not well managed).

With leaching, water management strategies would focus on the environmental management of leaching operations, with research aimed at reviewing the feasibility of dry disposal processes, the magnitude of water inflows and outflows, and the relative merits of chemical, biological and combination processes.

Flotation

Froth flotation is a process whereby differences in physicochemical surface properties are used to separate fine mineral particles liberated from complex ore bodies (Wills, 1992). Pulp is charged into the vessel and air is distributed throughout the flotation cell, for example by means of an impellor. In the process of direct flotation the mineral particles attach to the rising air bubbles, forming a froth layer at the top of the flotation cell. This layer of froth may then be scooped off and recovered as product.

To prevent the rising air bubbles from bursting and to ensure that a stable froth is formed, flotation requires a number of reagents. Successful flotation relies on a well balanced chemical budget. Any water management initiative that has the potential to alter water quality (e.g. internal recycling or use of saline groundwater) can impact on this operation.

With flotation, research should be aimed at better understanding the link between water quality and flotation. Previous research has already indicated that some heavy metals and organic matter could greatly influence the success of flotation performance.

Dewatering

Dewatering processes separate water from mineral slurries to yield a concentrate with high percentage solids. There are various ways to achieve this, through sedimentation, filtration, thermal drying or paste technology. Reagents are primarily used for coagulation and flocculation to aid filtration. The water that is recovered during dewatering typically progresses to a nearby water holding dam or a tailings facility, from which it is then recycled to the concentrator. As discussed above, there are a number of technical challenges associated with recycling tailings water containing a variety of chemicals over a range of pH. Any progress on understanding the impact of varying water quality on unit operations would impact on the likelyhood of using tailings water.

Summary

The major issues identified at the level of unit operations are that:

1) Technological advances could be explored to use less water for a specific process.
2) There is a lack of knowledge about the interactions between water quality and performance of unit operations, which limits uptake of opportunities for chemical synergies and improved water management.
3) The relationship between water volume and flux rates and energy efficiency or consumption is not a primary consideration in the design of unit operations.

The suggested research response is to develop a catalogue of unit operation options for water use, chemical conditions and interactions with minerals, improved synergies and constraints to efficiency, and energy consumption and efficiency. Such a catalogue would facilitate comparing unit operations, modelling of various combinations and selecting a design based on operational and sustainability objectives. The process of populating the catalogue would identify gaps, i.e. where information on water-related efficiencies and costs is currently unknown, and highlight where certain desirable options are currently unavailable. A tool could be developed to make the catalogue available on-line. A suitable model for an on-line tool would be a free access for minerals companies, with suppliers subscribing to make their information available, thereby creating a commercial opportunity for CSRP to provide an industry service.

4.3 Level 2 – The Processing Plant

At Level 2, unit operations are combined to form a process chain which represents the minerals processing plant (Figure 5). At the previous level, we looked at ways that less water could be used for a particular operation. Now we look at the impact of implementing these strategies on the other linked operations. For instance, a change brought about to improve the operational efficiency in one unit operation may impact on the performance of downstream processes. At this level, the focus is on the interactions between unit operations.

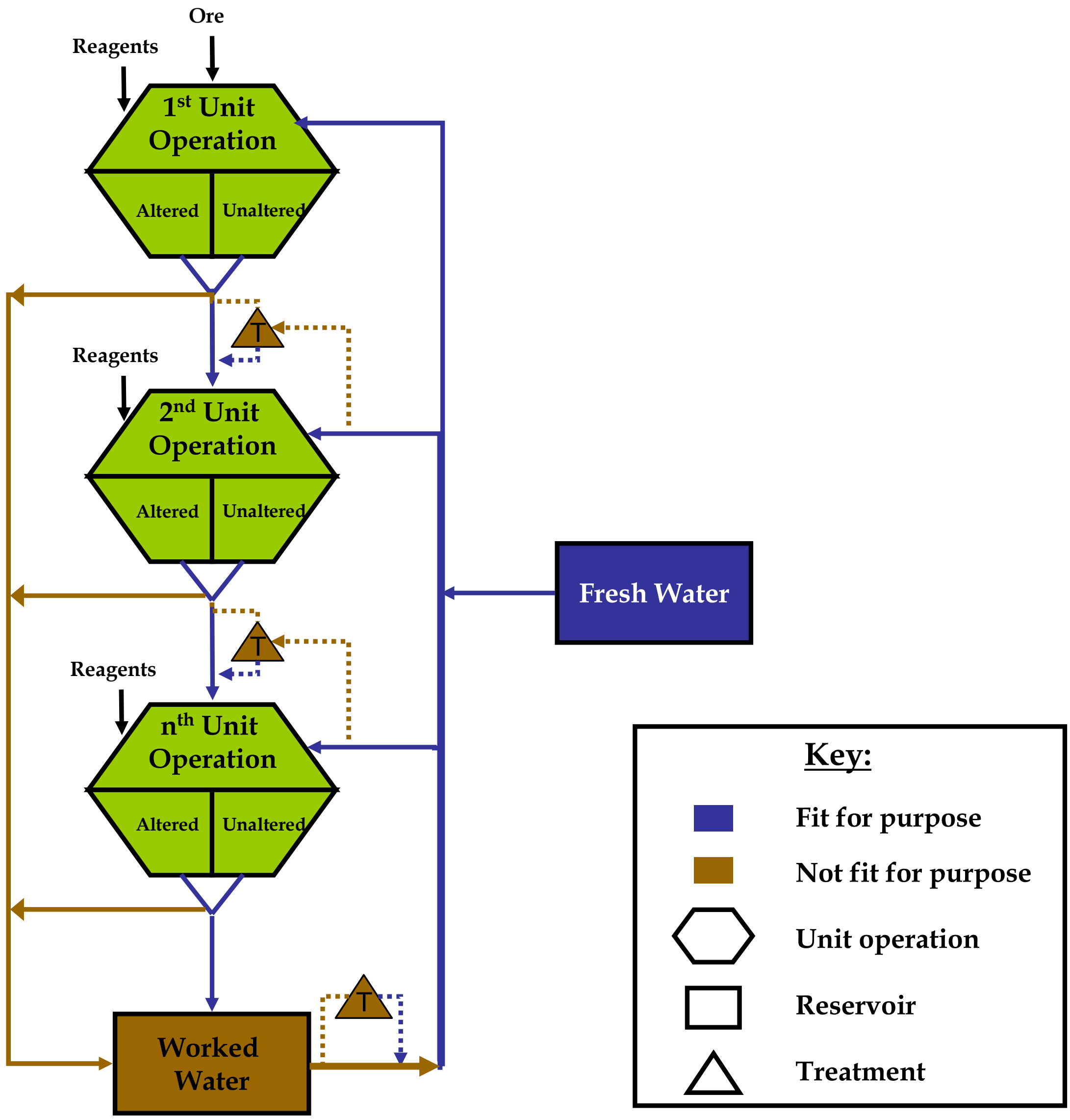

Figure 5 - Conceptual model of the processing plant based on unit operations (described by water, reagent and energy use and performance efficiency).

A typical water management strategy could be external recycling, where water is recovered from a unit operation, stored in an appropriate water system, and may again require treatment before being used again by downstream operations.

Reagents may be added to any or all of the unit operations that constitute the processing plant. Within each unit operation, the fresh reagents and those carried over from downstream operations can either be altered or they may pass through the system unaltered. Altered reagents include those which are consumed, and those which interact (including interactions with both water and ore). If the reagent is altered in a negative way, the residue water may require treatment prior to entering a downstream unit operation to ensure that it is fit for purpose.

The challenge here is to understand all of these interactions so that improved water management does not impact negatively on performance. The potential for synergies should also be explored.

Issues of concern were discussed during one-on-one interviews with key industry contacts, site visits and the two-day structured Industry Roundtable. This led to the tabulation of issues and associated research responses as summarised in Appendix C (Table 9). General comments are provided below.

When attempting to represent processing plants as single unit operations linked by water, reagents and energy fluxes, it was found that:

1) There is little data providing both water quality and quantity information for a particular processing plant. While some sites published useful quantity information, information regarding the types of reagents used was not provided. Conversely, sites that published selective information about their reagents failed to publish sufficient water balance data.
2) External recycling can definitely impact on performance (e.g. copper selectivity and recovery at Boliden Minerals), thereby demonstrating the importance of understanding both the physical and the chemical interactions between adjacent unit operations.

Numerous examples were compiled, demonstrating good practices and innovation, from design stage to operational stage. As an example, at design stage, during feasibility studies for a new processing operation, an audit of potentially available water resources was conducted from a quantity and quality perspective. At operational stage, a heap leaching area was divided into cells to optimise water recovery and recycling. Some sites have clearly understood the importance of interactions, and have kept their water sources separate so that there is a range of different water qualities available onsite and that the water of least acceptable quality is provided to each application. These examples could be extended to a wider section of the industry, provided there is supporting information for quantifying the differences in water, reagents and energy uses from one set of linked unit operations to another.

Data on water use for specific unit operations were very difficult to locate. Information is often aggregated across several unit operations, and the data are either scattered in corporate reports or are embedded within detailed technical descriptions for a particular process. These issues make it problematic to extrapolate data to the industry in general. Although an attempt was made to summarise typical water use figures for common mineral processing operations, publicly available water data were found to be too site specific to be generalised across the minerals industry. This variability was also recognised by Norgate et al. (2006). This presents a key issue in that benchmarking the performance of linked unit operations becomes difficult. A repository of information would allow such comparisons to be made within a suitable framework.

Another issue that makes compiling water information difficult is that there is general consensus within the industry that it is impossible to accurately compare water use efficiency between two operations. Typical comments included: "Every mine is different so you can't compare operations.', and 'There are no standards for comparison between sites.'. This issue was encountered first hand when compiling this paper. Comparing operations or sites is important as an operation can draw on the good performance of another to improve its own processes. It would also assist the industry in developing 'best' or 'leading' water management practices, thereby displaying leadership in the field of water management. The use of an organising framework such as the one presented in this report would provide a basis upon which operations could be compared.

Such a tool should allow the estimation of overall system performance in terms of expected output, e.g. mineral recovery or commodity purity level, operating and maintenance impacts on profitability and contribution towards sustainability objectives. To achieve this it would be necessary to quantify the implications of linking one unit operation with another (potentially as selected from the catalogue outlined above). These implications include necessary operating boundary conditions, e.g. pH or temperature, and known potential synergies, compromises and antagonisms between operating conditions (upstream and downstream).

A plant water balance is essential to assess and benefit from potential performance improvements. This requires monitoring of water flows and storages. Opportunities exist for providing tools to analyse and design monitoring systems that will provide sufficient information to develop a water balance that is tailored to the specific operation for a reasonable cost.

4.4 Level 3 – Site Water Tasks

Level 3 is a system representation of the whole site or operation. The processing plant is one of the building blocks of a larger operation, which may also include extraction (mining), tailings facilities and other water tasks, e.g. dust suppression. Like the interactions between unit operations within the processing plant, interactions between major site processes are the focus at this level. For example, the influence of local climatic conditions, such as rainfall variation, raises significant issues regarding water supply and water quality variation. Also, prioritisation of water and energy for various processes must be dealt with.

An example of a system representation is provided in Figure 6.

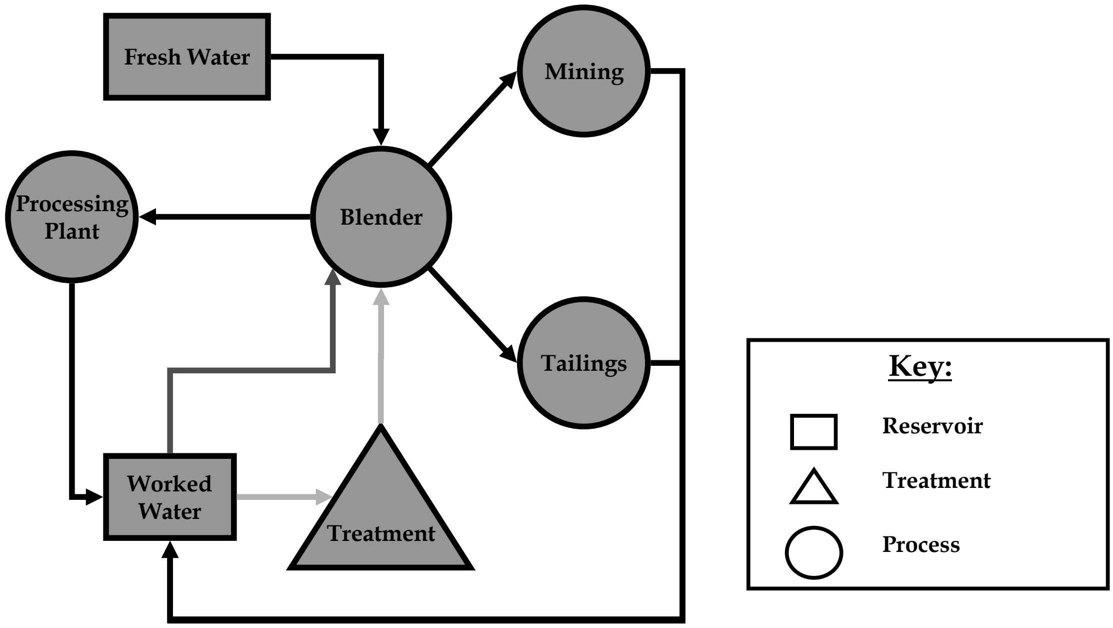

Figure 6 - Conceptual model at a site level

Again, through consultation with the various industry contacts, numerous examples were compiled demonstrating good practice, such as detailed records of site water balance, innovation in discharge management, existence of dedicated on-site water management teams, use of aquifer re-injection to maintain water levels, water quality monitoring etc. The general issues that were mentioned by industry generally relate to objective setting, guidance for standards, accurate costing of water supply, and lack of contingency planning and risk mitigation (Table 3 in Appendix C). More precisely, the main issues and research priorities at Level 3 are that:

1) Site water management becomes disaggregated because the water is managed as though it was only part of each component rather than connecting between most (or even all) components. This results in significant difficulties in improving water management because of the lack of integration of planning and operational water management. Consequently, implementation of actions to meet sustainability goals can be very difficult. Formation of a site water committee is recommended. Research into whether this in itself results in improved management would be valuable. If not, additional process improvement may be needed.
2) As sites increasingly reuse more water, the processing system can become more susceptible to variations caused by changes in the site water stores due to evaporation, seepage, rainfall and groundwater flows. There are

few tools available that operations can use to understand how variation in climate influences resource processing performance. An appropriate research response includes provision of information explaining which water constituents may cause difficulties and under which conditions. This should be combined with information on the likelihood of processing constraints arising as water moves around the site under various climatic conditions.

3) The conditions that must be met for acceptable closure of operations and/or components of operations are becoming increasingly stringent. Long term water management is one of the main aspects of sustainable closure. Research that provides practical information on strategic site water planning and ongoing operational water management to assist achievement of desirable landscape endpoints after closure is a priority. Integrated approaches are particularly desirable.

As with Level 2, tools that can provide water balance calculations supported by appropriate monitoring are needed.

4.5 Level 4 – Site as a Unit

At Level 4, the site is dealt with as a single unit. Water, energy and reagents are considered from the point of view of the overall inputs to and outputs from the site. Non-technical issues are introduced, representing the site's interactions with the outside world. These issues usually include company policy requirements, government regulations, expectations of the surrounding community and environmental considerations. All of these can influence the operating conditions (Figure 7).

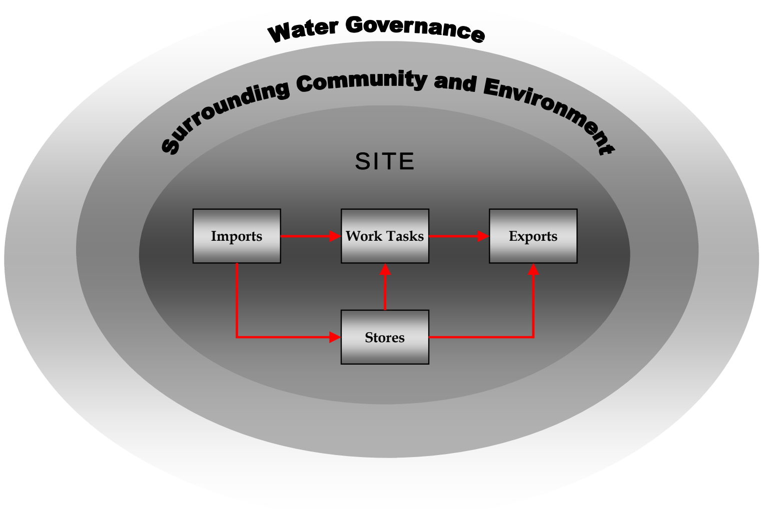

Figure 7 - Various layers of information at the site level

Issues of knowledge and data management, and comparison between operations arise at this level (Table 11 in Appendix C).

Organisations worldwide are beginning to recognise the importance of effective knowledge management. Each site is expected to secure necessary water supply (e.g. to avoid production losses due to water shortages) and to meet disposal requirements at minimum cost. This requires good risk management of a necessary input. Additionally, the costs associated with treating, delivering and disposing of water are often not fully understood. To keep track of all costs relating to water management, effective knowledge management systems are required. A site that lacks such a system may lose valuable information when key staff members leave the organisation. It is also essential that daily operations data are monitored so that process improvements may be recognised and implemented. The conceptual model outlined here can be used to help design the information management system, as it provides a basis for locating significant water flows and qualities, provides an overview of the water management system so that staff training is facilitated, and can guide the structure of reporting formats.

In an industry where decisions to proceed (or not) with an initiative or project are based on a sound business case with reasonable rates of return, it can be difficult to make a case for projects related to water that meet the necessary thresholds. This is exacerbated by the fact that the price of water is low (sometimes zero) and the proportion of the total business cost structure related to water is trivial once delivery infrastructure is in place. However, it is rare to see full accounting for all costs. Therefore, effective knowledge management and recording of water management costs could also help with making the business case for water-related projects.

Being able to compare operations is important because if the industry is not proactive in that domain, other organisations (such as non-government organisations) will draft comparisons. It is considered better to have ownership of how the comparisons are carried out. Comparing operations could also lead to the adoption of 'best' or 'leading' practices, thereby displaying industry leadership in the field of water management. It would help diagnose water management issues and associated opportunities for solving them, without having to analyse the problem in too much detail.

Broader, less technical concerns were also found, including community concerns (particularly over the cumulative impacts of a site), competition for water, change in regulations, and overallocation of regional systems (particularly groundwater). The social license-to-operate is threatened by societal opinion on justifiable uses for water, and community expectations should be analysed.

Research responses at this level should include:

1) Development of integrated systems that meet the multiple site information needs to address knowledge and data management issues. Systems models which allow valid comparison between sites – as a vehicle to improved overall water performance – are needed.
2) In cases where government policy is written on the basis of the precautionary principle, industry should invest in obtaining all necessary information to facilitate a switch to evidence-based negotiations for policy developments, so that debate is not clouded by emotions or pernicious marketing.
3) Social research is required to better understand successful approaches to community engagement to ensure reasonable compromises are struck between community end points and company financial and governance limitations.

4.6 Level 5 – Linked Sites

At Level 5, systems that comprise linked sites are represented (Figure 8). Linkages may either be physical flows (e.g. ore, water, chemicals or energy) or they may be information flows (e.g. corporate policies and targets, legal agreements).

A group of independent corporations may develop physical links to exploit synergies, based on the concept of 'industrial ecology', which is so named because of the analogy with an ecosystem which typically evolves such that the waste from one process/species is the feedstock of another. In the industrial version, direct sharing of energy is also exploited. For instance, cogeneration provides the opportunity to capture the byproduct heat of power generation into a heat source for another industrial process.

The simplest, and perhaps most common synergies, in practise, are those where one operation takes the wastewater from another as all or part of its input. Many examples exist where treated effluent is used in this way. For example:

- QAL receives treated effluent from the Calliope River Sewage Treatment Plant for use as red mud wash water (Stegink et al. 2003).
- Cadia receives approximately 13 Ml/d of treated effluent from the Orange Sewage Treatment Plant (Orange City Council, 2003) as import into their water supply.
- Port Kembla will soon receive recycled effluent from the Wollongong Sewage Treatment Plant and will use it for cooling towers and dust suppression.

Kwinana has also been very successful in creating a range of regional synergies (Corder 2005; van Beers et al. 2005).

Other types of site networks exist that may be geographically widespread. For example, all operations owned by a particular company may have certain operational guidelines associated with company efficiency and/or sustainability policies. They are thus part of a system linked by policy. Similarly, the concept of product stewardship may result in operations becoming linked as a result of their being upstream (or downstream) in the commodity chain. Sustainability goals in one or more companies or even government policies may provide these links.

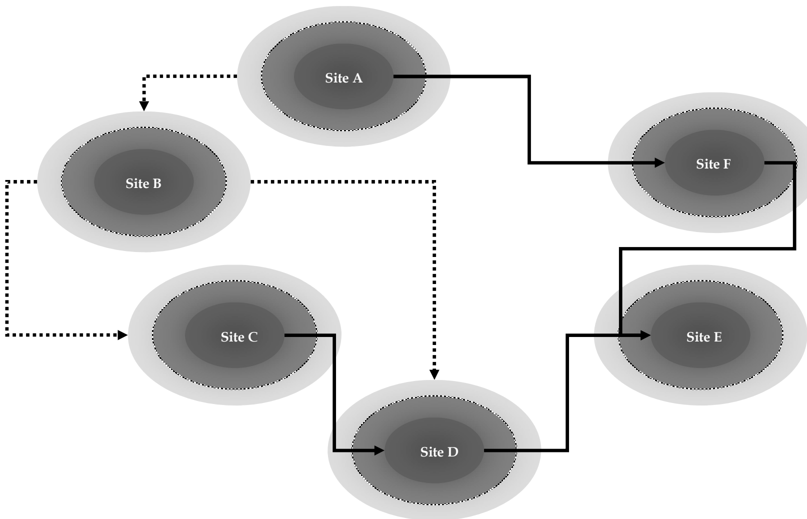

Figure 8 - Conceptual model demonstrating interactions between linked sites. Broken lines indicate information linkages and solid lines indicate physical linkages.

Opportunities exist to quantify these benefits and to attempt to understand the limits imposed by reporting benefits that accrue to one company from another's actions. When the manufacture of a product requires involvement of several operations, reducing water use in one operation can increase the water use in another operation. An example would be an increase in the use of salty water requiring more fresh water imports in downstream operations. Therefore, it can be difficult to identify and credit the process responsible for changes in water management performance.

As one example outside the resource processing sector, Unilever have modified their approach to communicating water management improvements from solely measuring the company's own water use in its operations to analysing its overall water imprint, taking into account water used by suppliers in growing raw materials and water used by consumers in using Unilever products.

Significant research opportunities also exist in deepening the concept of industrial synergies from the current approach which is limited to consumption of waste. In ecology, ecosystems are referred to as being resilient because they can cope with disturbances without shifting into a different state, and the process of rebuilding after a disturbance actually promotes renewal and innovation. Resilience is usually related to how much shock a system can absorb, and the degree to which the system can build capacity for learning and adaptation. These ecological concepts should be applied to industrial synergies, so as to create industrial complexes that can cope with changes (economic, social, and environmental), are innovative and highly adaptable. This is a research agenda that combines leading intellectual development with practical outcomes and opportunities.

Chapter 5 - Integration through Sustainability

The final part of this paper addresses some challenges associated with using sustainability principles to meet operational needs. It is proposed that the integrative nature of sustainability be used as a mechanism to bring together the multiple demands on operations. To achieve this, practical tools are required to connect institutional policies to operations. This should be complemented with working definitions of concepts relating to sustainable practices because many people hold different understanding of the same words relating to sustainability.

The hierarchical model proposed provides a structure and strategic base for planning and information management. Figure 9 shows that there are a number of industry and government policies and guidelines which aim to assist sites to operate sustainably. Most companies have participated in the formulation of the ICMM principles for sustainability through the MMSD process and Global Reporting Initiative (GRI). In Australia, the MCA's *Enduring Value* document provides guidelines for implementation of the principles. More recently the Ministerial Council for Minerals and Petroleum Resources and the MCA have jointly produced a *Strategic Framework for Water Management in the Minerals Industry* (Minerals Council of Australia and Ministerial Council on Minerals and Petroleum Resources, 2006). The document lays out the components that should be addressed in meeting the range of management requirements associated with water for an operation to be considered sustainable.

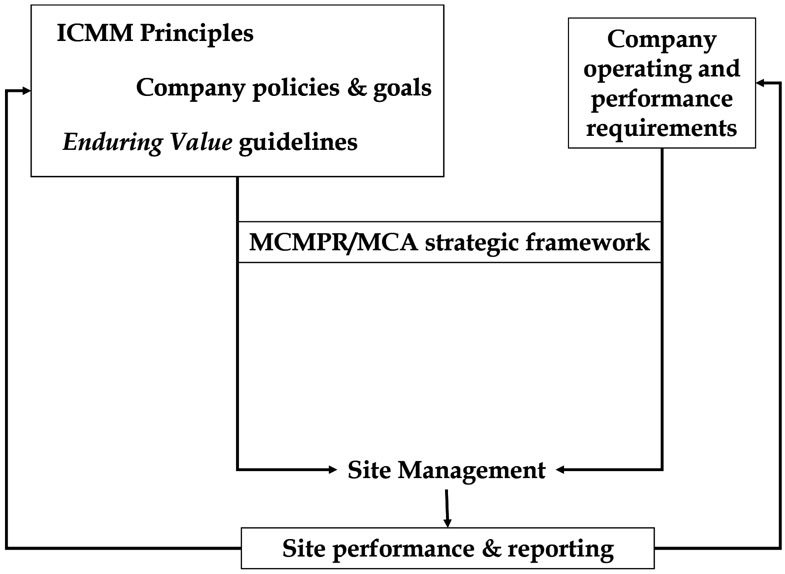

Figure 9. Relationship between industry, government and corporate policies and guidelines and site performance.

This paper attempts to deliver information and a conceptual approach to aid implementation of these policies and the strategic framework (Figure 10). This is achieved by taking a technical view of the resource processing operation as opposed to approaching it from a comceptual point of view. The hierarchical conceptual model proposed integrates activities from the level of individual steps of a processing operation to linked sites in an industrial ecology context. Clarity in stating sustainability and operational water management objectives and ownership of their resourcing and implementation are seen as critical needs. By adopting a technical (as opposed to more abstract) approach, sites can more readily identify with the objectives and more easily incorporate them into day-to-day operations. This should help relieve a major issue with water management in the industry, i.e. linking corporate and government imperatives to daily operational performance pressures.

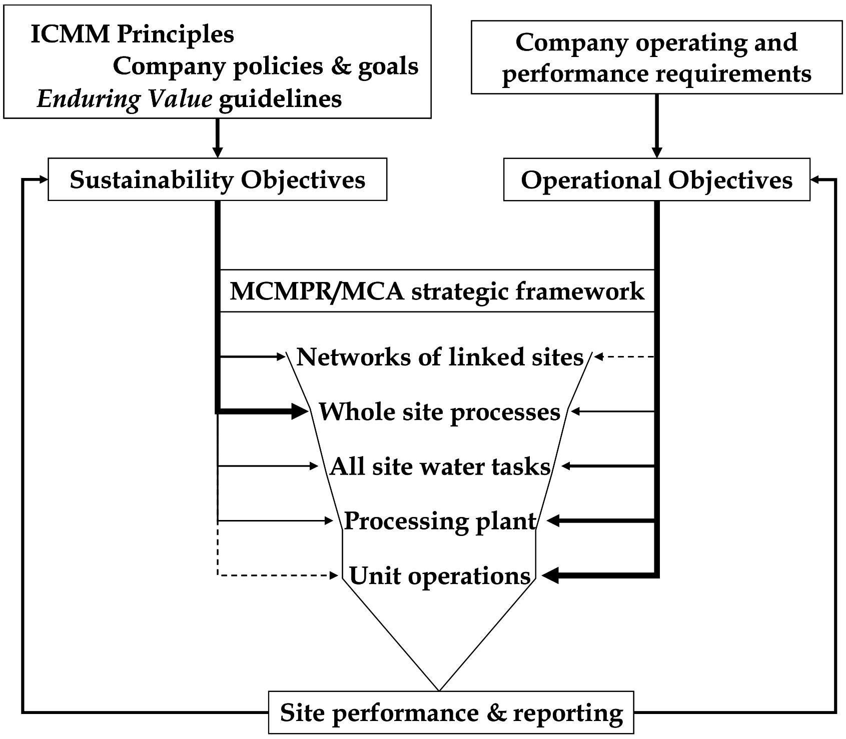

Figure 10. Proposed process for linking sustainability and operation objectives for water management with levels (from networked sites to unit processing operations) at which water is managed.

A number of conceptual issues related to sustainability have been raised as potential impediments to progress. Industry representatives have repeatedly expressed frustration with the difficulty of making a sound (financial) business case for further improvements in water management. Very often, obvious improvements to water use efficiency have been implemented - particularly in urban areas – and water use has been reduced (Figure 2). Then, given that water prices are not excessively high and water costs are not a large proportion of operating costs, companies find it increasingly difficult to make a financial case for additional water management improvement projects. With consistent calls for improvements in water management from community, government and corporate policies an apparent conundrum arises. How does an organisation that exists to return profit to shareholders justify investing in water management which is not required by law and has a negative net present value? The response to this question is that companies are now operating to a broader agenda than short-term profit maximisation and that management of risks associated with water requires a broader view than water price, supply and disposal costs. There is substantial interest, therefore, across the industry in developing a more profound concept of the value of water and to complement this with practical tools for its use in decision making. This is likely to be a fruitful area for research.

One source of confusion over water initiatives is a failure to separate two fundamentally different types of sustainability/water situations.

Mode I) *Production driven with sustainability benefits derived*. This is where development or change to a water system is required to meet production needs and, if it is done in a particular way, benefits consistent with sustainability goals can also be delivered. If the project can be delivered with acceptable financial returns and deliver sustainability benefits (for 'free') then it will likely proceed. However, if there are additional costs involved a more difficult decision arises. An example chain of logic might be:

a. The mine production over the next 5 years will increase by 30% which will require expansion of the mineral concentrator;
b. Expansion of the concentrator will require more water;
c. Access to additional water is possible by purchase on the local water market and the price is reasonable. The local town will need to be put onto permanent water restrictions as a result;
d. The additional water could be made available by treating water from the tailings stream. Water treatment is more expensive than water purchase.

In this example, a trade-off between production costs and community benefit (e.g. water access for amenity – gardening and sporting facilities) exists. The sustainability benefits can be delivered, but at a cost greater than the cheapest option.

Mode II) *Sustainability driven*. This is where a project or initiative is developed with the objective of meeting a goal of sustainability as the driver. For example, a chain of logic might be:

a. Globally fresh water is increasingly scarce compared to need;
b. Our company uses significant fresh water;
c. We should reduce our fresh water use to help relieve the scarcity problem making a positive contribution to global sustainable development goals;
d. All operations will be set the objective of reducing their fresh water consumption by x% with respect to production.

Clarity over which of these cases is being dealt with can alleviate some of the confusion surrounding the business case conundrum. (Mode I is normal business expenditure where cost is minimised to achieve the necessary operational outcome).

A considerable constraint in moving to more sustainable operations is what might be termed technology inertia. This is where more sustainable options are seen as risky and potentially costly. This is not necessarily because of poor design or operating inefficiencies (many are the contrary to this) but because of the risk of changing from proven approaches and technologies. For example, companies may select a particular concentrator design because of its similarity to others that they operate. This has to do with cost-efficiency of design and construction and operational efficiency with maintenance and labour familiarity. A research response is to conduct rigorous analysis of the correctness of the assumption that following a well-trodden development and technology path is cost-effective compared to innovating with more sustainable options.

As indicated in Sections 4.2 to 4.6, industry participation in the project led to the tabulations of issues for each level of the conceptual hierarchical model. These tables are provided in Appendix C. They provide a receptacle for addition of issues that have not been raised or captured in this initial process. CSRP could develop an on-line capability for industry to browse and add to the water issues. This would create a 'living' repository of information on industry water issues. A research agenda for CSRP could be compiled by selecting from these lists and investing in line with industry-derived prioritisation of the issues raised.

However, an opportunity of significantly greater reach for CSRP emerges. It is to design, implement and test tools that will link operational/technical performance imperatives for water management to sustainability objectives. This would include consideration of energy needs/efficiency and chemical interactions. No such integrated tool exists. Development by CSRP, with industry support, will demonstrate a logical and powerful approach to industry leadership. It will supply a novel reporting capability which integrates the linkages inherent in sustainability thinking. An example of one suitable conceptual model upon which this would be based is presented in this paper. Such a tool could be designed to be developed in modular fashion producing a commercial output from CSRP that would grow over time.

Chapter 6 - Conclusions

The review of water issues associated with the production of alumina, steel, gold, coal, mineral sands and uranium shows that the minerals processing industry could improve its water management strategies, and that there are several levels at which this could occur, from specific technical improvements for a particular process (e.g. address the impact of water quality on flotation processes to increase water recycling), to increasing linkages between site operations and responding to community pressures. An organising framework, based on the building blocks of mineral processing operations, is proposed and potential research topics are offered at each framework level.

At the level of the unit operation, it is suggested that CSRP develop a catalogue of options for water use; chemical conditions and interactions with minerals; improved synergies and constraints to efficiency; and energy consumption and efficiency. This could be developed as an on-line tool provided by CSRP as an industry service, which companies could use to compare options for unit operations in terms of water, energy efficiency and trade-offs.

At the level of the processing plant, there is a need for a tool or information database for quantifying the differences in water, reagents and energy uses between one set of linked unit operations and another, enabling the estimation of overall system performance in terms of expected output (e.g. mineral recovery or commodity purity level); operating and maintenance impacts on profitability; and contribution towards sustainability objectives.

At the level of the whole site, the issues that should be addressed are: whether managing water in an integrated manner results in improved management (and if not, propose additional process improvement), developing a better system management of recycling and reuse, and providing practical information on strategic site water planning to assist with achieving desirable endpoints after mining. Developing integrated systems that meet the multiple site information needs is recommended. Systems models that allow valid comparison between sites – as a vehicle to improve overall water performance – are needed.

An opportunity of significant reach for CSRP emerges. It is to design, implement and test tools that will link operational/technical performance imperatives for water management to sustainability objectives. This would include consideration of energy needs/efficiency and chemical interactions. No such integrated tool exists. Development by CSRP, with industry support, will demonstrate a logical and powerful approach to industry leadership. It will supply a novel reporting capability which integrates the linkages inherent in sustainability thinking. An example of one suitable conceptual model is the hierarchical conceptual model presented in this paper. Such a tool could be designed to be developed in modular fashion producing a commercial output from CSRP that would grow over time.

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Appendix A. GRI Indicators

The 2002 Sustainability Reporting Guidelines contain six GRI indicators which are related to water, as summarised in Table 7.

Table 7 - GRI indicators relating to water. Source: Global Reporting Initiative (2003)

GRI indicator	Description
EN5: Total water use	Total water use may be represented by one of two figures: 1. The total withdrawal from all water sources. 2. The portion of that water withdrawal that is consumed within the operation (i.e. the amount of water that is not directly returned to the environment in liquid form).
EN12: Significant discharges to water by type	This indicator identifies water that is discharged to surface waters (including sewers that lead to rivers, oceans, lakes, wetlands and treatment facilities) or to groundwater, either through a defined discharge point (point source discharge) or over land in a dispersed or undefined manner (non-point source discharge). This category also includes wastewater removed from the organisation via truck. Both treated and untreated effluent discharges should be reported.
EN20: Water sources and related ecosystems/habitats significantly affected by the use of water. Include Ramsar-listed wetlands and the overall contribution to resulting environmental trends.	To address this indicator, an organisation needs to identify sources from which water is withdrawn and report on the impacts to those sources because of the withdrawal. The indicator makes specific note of sources and associated ecosystems. The most important ecosystems are rare or ecologically sensitive areas, including Ramsar-listed wetlands.
EN21: Annual withdrawals of ground and surface water as a percentage of annual renewable quantity of water available from the sources. Breakdown by region.	This indicator gives a measure of an organisation's relative impacts on local water sources in terms of annual quantities of water used versus the average annual renewable quantity available.
EN22: Total recycling and re-use of water. Include wastewater and other used water (e.g. cooling water)	The water re-use rate is a measure of water use efficiency. The rate is determined by the amount of water re-used by the organisation over a period of time, for a process that would otherwise be supplied by fresh water. Discharges to the environment may also be reduced through this practice.
EN32: Water sources and related ecosystems/habitats significantly affected by discharges of water and runoff. Include Ramsar-listed wetlands and the overall contribution to resulting environmental trends.	This indicator identifies the water bodies that receive water and pollutants from an organisation, particularly those water bodies and associated ecosystems known to be rare or ecologically sensitive, including Ramsar-listed wetlands.

Appendix B. Sustainability Criteria

Table 8 - Criteria used to assess company sustainability reports

a) Sustainability Strategy	
0	There is no evidence of SD. The issue is not addressed.
1	There is an explanation of why SD is not addressed.
2	SD is mentioned in the company profile, but with little follow-up information.
3	SD is defined in the company's broad strategy/vision/mission; but is not part of a broader framework.
4	The company has a framework for achieving sustainable development, but in broad terms rather than specific goals, targets or issues.
5	The company has a specific 'stand-alone' policy on SD; or individual, issue-specific policies.
6	The company sets specific targets for achieving SD, with targeted programs to achieve these.
7	The company has developed a framework for addressing SD in their day-to-day business systems, linked to objectives and supporting programs of SD.
8	There is a clear link between SD statements, policies, procedures, outcomes, data, research and implementation programs and business systems; SD is fully integrated into the strategic agenda of the company.
b) Water Issues and Performance	
0	Water is not identified as a key issue. Water is not addressed.
1	Water is identified as an issue of concern, but does not appear to be a significant priority.
2	Water is identified as a priority issue of concern, but is not explicitly linked to sustainability statement or goals.
3	Conceptual link is made between SD and water use, but there is either no operationalisation or measurement.
4	Links water to SD goals; reports on compulsory GRI water indicator (EN2), but does not go any further than is required.
5	Water is identified as a specific issue of concern; linked to sustainability policies; large range of measurements reported; specific targets or projects exist, however, actual performance is difficult to assess (due to quality or quantity of information presented).
6	Water is a key element of the SD strategy; and projects focus strongly on SD of water resources. This company is actively trying to improve its water use to achieve sustainability, and has clearly indicated success in this area.

Appendix C. Priority Issues and Research Responses

Table 9 - Issues and priorities at the unit operation level

Unit Operation/ Commodity	Issues	Research Responses
General	• It appears that sites lack information about water, energy and reagent fluxes between various unit operations. • The required water quality for specific unit operations is often not fully understood. • The conceptual model presented in this section does not fully define the features that characterise a unit operation. • Management lacks an understanding of the potential site technical issues resulting from implementation of water recycling initiatives.	• To gain the most benefit from the conceptual model suggested in this paper, a generic description of a unit process is needed that ensures the major sustainability and operational issues are dealt with effectively. For example, the operational efficiency of processes has not been considered here. • Conduct a data survey to quantify water, energy and reagent fluxes entering and leaving unit operations. This information would enable completion of the framework at the technical level. Such a tool would assist all parties to better understand the implications of proposed water management initiatives.
Grinding	• The impact of water quality on grinding processes and subsequent downstream flotation is not fully understood. • There are potential limitations to internal water recycling. • Microwave grinding may potentially eliminate water use.	• Consider the impact of water quality on grinding processes to assess the extent of water recycling that can be achieved
Leaching	• The pregnant cyanide solution recovered from heap leaching operations is often stored in ponds and may hence kill wildlife in the surrounding area. A dry disposal process would eliminate this issue (US Fish and Wildlife Service, 2001). • When estimating the leach cycle time and application rate, insufficient meteorological data can result in an inaccurate water balance (Burkhalter, 1999).	• Take a strategic look at leaching techniques, water inflows and outflows and the relative merits of chemical, biological and combination processes.
Flotation	• The impacts of water quality on flotation performance (particularly in sulphide and coal flotation) are not fully understood. • There are management driven limitations to the use of recycled effluent in flotation circuits.	• Assess the impact of water quality on flotation processes, with focus on the dissolved compounds that can have an adverse affect on the chemistry of the flotation circuit (soluble hydroxides, metal xanthates, organic matter) and on sulphide flotation and coal flotation.

Unit Operation/ Commodity	Issues	Research Responses
Dewatering	• Heavy metals are transported from the tailings dam to the surrounding environment. • The quality of discharge water from tailings dams needs to be considered. • There are technical challenges that need to be addressed in relation to the reuse of tailings liquor including solution chemistry, organics and contaminants. • The rate of evaporation from tailings ponds is significant. • Sites often have a lack of 'ownership' in relation to tailings dams.	• Research should be conducted into novel reagents/chemicals that can form more stable heavy metal complexes in tailings, thereby preventing the release of heavy metals into the environment • Compare the various technologies that may be used for dewatering, e.g. pastes, filter cakes and slurries. The requirements in terms of water, energy, reagents and complexity (including labour) should be considered.
Steel	• The iron and steel industry consume a significant amount of water for cooling purposes. There are limitations to the use of saline water due to scale formation and equipment corrosion. • Considerable quantities of water are used for low grade waste heat recovery from process streams and for onsite dust suppression. • Although some sites have collected urban stormwater for reuse within steelworks, there are limitations to this on account of debris in water, and government regulations.	• Consider novel technologies to enable low grade waste heat recovery without the use of water. No such technologies have yet been commercialised • Investigate economically viable alternatives that could be used within the steel industry for dust suppression
Alumina	• On account of the cyclic climate in areas of operation, water is commonly stored during winter for summer use. This is associated with a large evaporation loss from storage areas. • There is a large water loss during calcination; no processes have yet been developed to enable this water to be recovered economically. • It may prove economically viable to reuse secondary effluent if the costs were shared (valued by the state).	• Investigate technologies that could potentially be used to prevent evaporation from storage dams • The impact of precipitate management is poorly understood; it requires a full cost assessment. Research should be done into the precipitation of contaminants such as sulphates, jarosite, gels, and organics. • Changes in process variables that affect the rate of precipitation should be investigated.

Table 10 - Issues and research priorities at the site level

Component	Issues	Research Responses
Operations	• A set of objectives is needed that specifies operational requirements for different components within the system. This would involve a set of negotiations regarding which scenarios may be considered 'best case'. • There is a lack of guidance for acceptable standards for monitoring a site water balance. • There tends to be a lack of contingency planning and risk mitigation in relation to water • Costs of water supply are not always fully obvious • A better understanding of disposal costs is needed to help justify water efficiency.	• Guidelines are needed that can assist sites in developing a 'good practice' water balance. • Compare the issues associated with managing water from a site vs. regional level. Develop guidelines for the effective management of water resources. Such a project would involve comparing the costs and benefits associated with central vs. remote water planning/action teams.
Management	• There appears to be a lack of knowledge about how water management in one component of the system affects the performance of others. This requires evidence-based negotiation over site component changes. • Within a single company, some sites tend to be more effective than others at water management. Company internal analysis has found that leading water performers have clear accountability for water at the site level. • Separate site responsibilities tend to result in fragmented planning with undesirable consequences. • There tends to be a lack of coherence between site planning and natural areas of responsibility and ownership. For example, while the concentrator may be responsible for operating the tailings facility, the environmental department tends to be responsible for incidents by default.	• Research is needed into how to improve the level of transparency within a site, i.e. how can management ensure that there is widespread understanding about the issues that impact various components of the system. • Development of systems that can be used to assess the impact of corporate planning systems (i.e. how site responsibilities are allocated) on the effectiveness of water management.

Unit Operation/ Commodity	Issues	Research Responses
Energy	• The trade-offs between water and energy uses for available water treatment technologies are often not well understood. This complicates the decision as to which technologies are most attractive from a sustainable development perspective.	• Develop a management tool that is able to record and predict the energy demands throughout a total system. This tool could be integrated into a similar water management system. • Develop a tool that provides a link between the water use, energy use and carbon dioxide production associated with available water treatment technologies. Such a tool would enable management to make clear comparisons between alternative water treatment technologies

Table 11. Issues and research responses at the level of the operation as a unit.

Component	Issues	Research Responses
Community	• Often there is significant overlap between the workforce and community membership either as direct employees or as indirect support services and businesses. Therefore, the workforce has to live in environmental conditions that might result from the operations, e.g. air and water quality implications. • Community concerns are important to company sustainability management. There may be difficulties in managing relationships between local communities and operations that are driven by corporate goals. Therefore, site management may have difficulty 'signing-on' to implementing goal, particularly if in doing so production targets are compromised. • In some regions cumulative impacts, e.g. water quality deterioration of recreation areas, from resource processing operations are not 'owned' by any single operator and not owned by a collective. This may result in community frustration because it is difficult to get collective action/mitigation of problems. • Communities may be in direct competition for water with resource processing operations but unable to compete in a market for access to the water.	• It is often not recognised that the complexity of sustainable development may require new methods and skills in community engagement. There is a priority need to understand the differences in community engagement under a site-by-site legal compliance approach and an integrated sustainability approach. • Research into the nature and operation of water markets is required to understand how water allocation between resource processing and community potable uses can be secured.
Governance	• A change in the nature of regulations is needed; they should apply to the best use of water rather than 'blanket' rules. • Regulators to not fully understand the water demands of many businesses • Groundwater systems tend to be over-allocated and there is pressure to reduce allocations	• A more effective method to regulate water use needs to be developed. • A research priority is to define the areas of weater use and management where there is insufficient quality of information upon which negotiation over policy can be effectively undertaken. In such cases, government policy often takes a conservative precautionary approach. It is incumbent upon industry to provide information using non-biased sources to

		facilitate an open negotiation of positions. • Information on industry water use and efficiency needs to be compiled and communicated so that debates with community and government over security of water allocations are underpinned by information rather than dominated by emotion and/or pernicious marketing by other competitive water users.

Table 12 - Issues and research priorities for linked sites

Component	Issues	Research Responses
General	• Sites that develop physical linkages need to recognise that information links are also present. • It is often difficult to get two separate parties to appreciate the mutual benefits of synergistic relationships.	• Better modelling tools should be developed to demonstrate a wider range of potential synergies (and their benefits) to complement the current documentation of existing case studies.
Physical limitations	• Geographical limitations may prevent potential synergies from being exploited	• Investigation of options for cost and risk-sharing that will make synergies more attractive by overcoming too narrow a view of how profitable linkages can be implemented.
Risk	• Corporate risk - if a site receives recycled water from another, its water supply may be threatened by site closure or a change in ownership. • Operational risk - the receiving site needs to be confident that its partner will supply water in the appropriate quality and quantity.	• Investigation of appropriate legal instruments to m minimise risks. • Research to achieve a better understanding of how appropriate levels of control can be realised to provide resilience in networks not just linkages.
Operational opportunities	• Alumina producers generate water with high Na^+ concentrations that may be valuable to sites which require salt for neutralisation. • Water quality and precipitation may be interactive.	• Consider how to put together information sources that deal with water constituent requirements ands sources not just focus on water volumes. • Investigate potential sources of neutralising cations (e.g. Mg^{2+}) and uses for outflow waters with high Na^+ concentrations. • Investigate positive synergies that may be derived from water quality and precipitation