HOME

Systems Modelling for Water Management in Mining and Minerals — Bowen Basin Coal

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ABSTRACT

For nearly two decades water scientists have been debating the need to use appropriate models for the questions being asked and the data available. This paper puts forward a rationale for a hierarchical framework for water balance modelling as it applies to mine sites. The hierarchy is based on the complexity of models and their data requirements. Scientific models are the most complex and require the most data; next is engineering models, then systems models and the simplest representations are given by conceptual models. A position is put forward that systems models have a range of uses that the others do not provide. A systems model, called SiteMiser, is described and its calibration illustrated. The model is applied to seven coal mines from the Northern Bowen Basin in Central Queensland. Currently, there is little relationship between total water use and coal production. This relationship is not any stronger when fresh (raw) water is compared to reused water. Leading practice water use levels are simulated for all sites. The simulation results demonstrate that there is considerable opportunity to reduce water consumption and, in particular, to import less fresh (raw) water to the sites.

INTRODUCTION

The contemporaneous rapid increase in computing power and accessibility of various codes for simulating water flows in the late 1980s and early 1990s led a number of scientists to sound warnings about the (un)believability of simulation outputs. Beven (1989) raised the prospect that uncertainty associated with modelling water flow in catchments could render model outputs inaccurate in spite of the fashion for increasing the number of physical processes represented in the model mathematics. Philip (1991) expressed concern that increasing activity in modelling water movement in soil was not matched by commensurate increase in data to support modelling either from field observations or from laboratory experiments. Philip described his outlook on modelling in the immortalised quote:

> *Modelling is rather like masturbation – a pleasurable and harmless pastime just as long as you don't mistake it for the real thing.*

In the context of water and crop modelling, Passioura (1996) likened model outputs to snake oil because of the undisciplined practices of adjusting model parameters to match data rather than to question the model parameters. He asserted that it is hard to see how one can learn anything new from such a practice.

Whilst Philip and Passioura essentially made their criticisms and moved on, Beven has persisted in evolving the modelling concepts needed to overcome his criticisms (Beven, 2006). Beven's philosophy revolves around the reality that multiple model formulations may be equally valid representations of a system, given available knowledge and data, and an appropriate mix of modelling and statistics (generalised likelihood uncertainty estimation – GLUE) can help find the most likely solutions.

An alternative approach to this is to develop models that attempt to capture more the essence of the system than its details. With such models, it is important to ensure that one does not try to answer questions that require information about the details. The systems modelling discipline is well developed and takes a range of forms from qualitative 'box and arrow' descriptions to highly-developed conceptual, mathematical and philosophical approaches (Troncale, 2006). Applications range from hierarchical modelling of city traffic (Chabrol, Sarramia and Tchernev, 2006) to national health care systems (Fahey *et al*, 2004).

In a review closer to the field of application in this paper, Walker *et al* (2002) conclude that simple system representations, so-called 'top down' approaches, can be used to deal with the vexed issues surrounding estimation of deep drainage and recharge at the catchment scale. Simple conceptual catchment models have been used by hydrologists for decades (eg Boughton, 1984) and remain operationally useful (Bari and Smettem, 2006). Similarly, Lu *et al* (2004) demonstrated that a simple model of catchment/river systems could be used to locate areas for priority investment in landscape intervention for control of downstream fine sediment loads. It is important that a simplified model can be related to known physical principles so that the model can be used for more than describing a particular data set. Lu, Moran and Sivapalan (2005) have illustrated that sediment delivery ratio, a widely-used modelling approach for sediment delivery from catchments (or hill slopes) to streams; can be 'unpacked' to demonstrate consistency with an underlying physically-based interpretation.

In this paper, a systems approach is illustrated for mine site water balance modelling. The systems model is positioned with respect to other types of water balance modelling. A specific model example, called SiteMiser, is described and its calibration is illustrated. The results of applying the model for the comparison of the water balances of seven coal mines in the northern Bowen Basin are presented. The model is then used to explore the application of leading practice water use across the seven mines. A framework for setting water management objectives for the sites is used to do this. Ultimately, the aim is to demonstrate that a simple systems model is an appropriate tool for determining the priority areas for reducing water consumption on mine sites, thereby releasing water for other potential uses. This, therefore, supplies an important tool for sharing water to realise more of its multiple potential values. As a result, mining companies can make a contribution to sustainable development goals through a responsible use of water resources.

WATER BALANCE SYSTEM MODEL

Systems models compared to other model types

The site system model is a numerical description of the site water reticulation and storage configuration that brings together information on water flows (and potentially constituents) into a water balance. The amount of detail in the representation should be consistent with the uses of the model. It is important that the benefits of systems modelling are not seen as an alternative to operational site water balance models.

Figure 1 illustrates a range of model types in terms of the model complexity and their data requirements. *Scientific models* require the most data and tend to have the most complex representations. This is because the aim of these models is to

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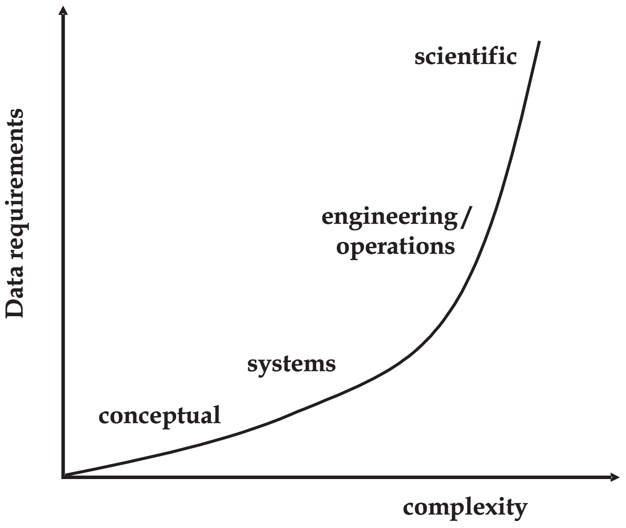

FIG 1 - Diagram illustrating the relationship between various types of models that might be used to represent and simulate options for mine site water management.

improve basic understanding of one or more system components. In many cases, scientific models will only represent part of the water management system but will do so in great detail. Generally, the limit to full system representation with these models is that even when data are available to run them, if too much of the system is included it can become impossible to separate model numerical effects from real system behaviour. The audience for these models is peers or engineers who have a specific interest in understanding part of a system with a view to reengineering it to solve problems or make operational efficiency improvements.

The models most familiar to water managers and consultants are the engineering models. These models attempt to represent all or most of the system and make acceptable approximations to overcome the difficulties associated with scientific models. *Engineering water balance models are necessary for operational (day-week-month) water management decision making and for detailed planning of major changes to the site and/or feasibility analysis and final planning for new projects.* Such models need to represent the details of site layout, pump rules and rates, hydraulics specifications, etc and have a time step and dynamic sensitivity appropriate to the operational decision-making time scale. The audience for these models is operators and engineering project decision makers.

Descriptive models provide a broad overview of the site needs, are generally generic, often diagrammatic and are used for purposes of explanation of how a coal mine site manages water. Their audience may be students or non-experts interested in the basics of how water management works and possibly how it relates to their part of the coal mine activities.

Between engineering models and conceptual models are *systems models*. These models attempt to describe the essence of the site water system without full detail of the site configuration. The roles they fulfil are:

- *Strategic planning*. Systems models allow early and relatively simple investigation of options and refinement of questions that will ultimately be answered using an engineering model of the site (or proposed project).
- *Site objective setting*. Given the demands set by various levels of management and best practice requirements, it is sensible to have a way of setting site objectives that does not require too much detail. Site water objectives can take many forms. They can range from a qualitative statement about improvement of processes and technologies, to careful monitoring of progress towards achieving quantitative targets. Depending on which variables are chosen for target setting it may be possible to compare a site with many others or only a few. In some cases, industry averages or leading practice values might be adopted as targets. Staff turnover is rapid at most sites and so new employees (and contractors) should be able to understand why any particular site objective has been set. The site system model can be a valuable tool to help set site objectives. By running various scenarios and examining the links between the model and water management practices the site staff can develop sound ideas as to how an objective might be achieved as part of the process of setting the objective. Comparisons with other sites, individually or as a group(s), can guide objective setting.
- *Performance reporting*. A critical aspect of performance reporting (and objective setting) is the communication between the players interested in the site performance, ie site staff, corporate staff and potentially various government agencies. A systems model has the advantage of allowing communication between these groups and agreement on objectives because they can work on the essence of the system without being side-tracked with, or confused by, unnecessary details.

  Performance is assessed by comparing data from the site, either from monitoring or modelling or both, with the site water objectives. It is important in reporting on objectives that reasons for meeting or not meeting objectives are seen as integral to reporting. Objectives can be written in such a way as to make reporting clear and simple. For example, the objective could include how it will be measured and what target values should be reached by what dates. Anglo Coal Australia has a set of performance indicators that were developed by engineering hydrology consultants (Water Solutions Pty Ltd), some of which could also be used for objective setting.
- *Site comparisons*. It is very difficult to compare different mine sites at the engineering or descriptive levels. This is because site particularities will be difficult to overcome. A systems model allows direct comparison of the main features of the sites. When differences are noted it will often be necessary to refer to an engineering model or detailed technical information to make decisions that will make one site look more like another, which has apparently better performance.
- *Industry benchmarking*. Because site comparisons can be made with systems models they are the most suitable tool for developing summaries of the performance of groups of sites, eg by company or region, or even the industry as a whole.

There is a degree of urgency in some companies to have a system in place through which the sites and corporate centre can communicate, set objectives and assess performance to ensure that both parties are working towards the same ends – security of water supply that meets production requirements without unacceptable environmental or social consequences. Therefore, this paper focuses on demonstration of the use of a systems model.

Scenario assessment is used to help set site objectives and to assist with understanding which water management practices are likely to be of importance for achieving certain objectives on each site. Scenarios are run by changing the values of variables in the site system model. Given that the site system model is likely to be a significant simplification of the site engineering water balance model it is important that results from the systems model are treated as 'order of magnitude' responses.

From a technical perspective there is a growing literature and expertise base on individual pieces of equipment suitable for mine sites that claim to be able to save large quantities of water (eg Mathewson, Norris and Dunne, 2006). Equally, there is increasing availability of water treatment solutions that are able to cope with most situations and are becoming more affordable. Whilst these claims may well be true, there is a degree of disillusionment on mine sites by people trying to justify to mine management various technical fixes that have appeared not to work in the past. Examples of this situation include dust suppressants, comprehensive water monitoring and desalinisation. This is unfortunate because it reduces uptake of helpful technologies and procedures. The systems level approach allows sites a clearer view of where they could potentially make significant progress and then seek technology to help them do so. A compendium of water management practices has been compiled to help with this issue (see: http://selkie.smi.uq.edu.au/waterminer/index.html).

Site system model (*SiteMiser*)

The model represents the water system as a set of water flows, each of which has:

- a quantity flux (volume per unit time) and potentially quality constraints, eg must be potable quality for showering; and
- limiting conditions, eg certain likely salinity concentration from underground pit dewatering, and/or specific requirements, eg minimum pH for coal flotation.

The water system is described as a set of water objects, which are connected together with reticulation infrastructure to form water flows. The four types of water objects identified are:

1. Imports – the places from outside the site boundary from which water is sourced, eg pipeline or aquifer.
2. Stores – the objects, within the site boundary, from which water is sourced and in which water is stored, eg in pit storages or dams. The sum of the water volumes in the stores is the site water stock.
3. Exports – the pathways and mechanisms through which water is transported across the site boundary and is thereby 'lost' from the site water stocks, eg seepage, evaporation, coal product.
4. Tasks – the activities that use, treat or manage water, eg coal washing, dust suppression and dewatering.

It is across the configuration of the water objects at a site that a water balance is constructed. For example, all site tasks should be in balance, ie the water exiting the task should equal that entering less any losses. Similarly, at the whole-of-site level the change in volume of water in stores added to the exports would equal the imports over a defined time period. The balances of constituents of the water, eg salt, are similarly constructed, measured and reported.

A generic model of a mine site was developed to quantify the fluxes of surface water, groundwater and worked water.[3] This model, called SiteMiser, is a considerably simplified system representation of a mine site.

It consists of:

1. two water stores, one for fresh water and one for worked water;
2. a blending facility, which is a piece of 'virtual' infrastructure representing all water reticulation around a site;
3. several users, which import and export water of varying qualities; and
4. a desalination plant.

Figure 2 illustrates the model components and flows of water.

Water enters the system as fresh water that is sourced from a pipeline, as aquifer inflows or as rainwater captured on site. Rain water captured on site may be directed to either or both of the reservoirs.

Salt is introduced to the system as a constituent of each water inflow. It is represented as a concentration associated with each of the water flows. Salt can be removed from the water circulation system by being stored on roads or swales, exported in the coal product or lost in seepage. The simulation model described above is driven for a duration that is determined by the rainfall sequence that is provided.

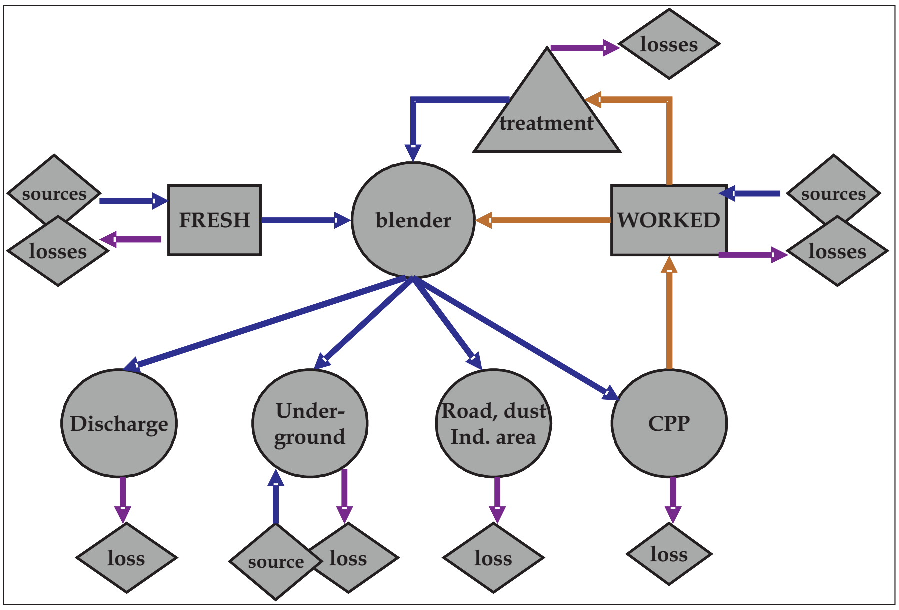

FIG 2 - System diagram of a simplified coupled salt and water balance model for a mine site (circles represent water using processes, rectangles are stores and diamonds losses and sources of water/salt).

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[3] Recycled/reused water is herein termed *worked water*, which is a term that indicates water has been used to perform a task and removes the pejorative implication that water becomes 'poor' or 'dirty' or 'contaminated' simply because it is not potable.

APPLICATION EXAMPLE

Regional background

The Bowen Basin is one of the world's important coking coal mining regions. The initiation of the *Central Queensland Coal Associates Agreement Act* of 1968 was the trigger for growth that has rarely faltered since – from 20 000 Mt in the mid 1970s to 140 000 Mt in 2005. Currently there are announced growth plans of unprecedented rates.

High level water information was compiled for 21 mines in the region from companies and public sources for the period 2003-05 (the most recent information was used wherever it could be obtained). Overall the sites drew in ~38 GL of fresh water and used ~52 GL of worked water over the period. These two volumes of water are not necessarily summed to provide a total because the time it takes a volume of water to recirculate is unknown. However, the sum of ~90 GL provides an indication of the quantity of water that would be required if fresh water was used for all processes (excluding recirculation within the coal preparation plant – the additional volume required if this was a 'once through' process would be far larger than indicated in the table). The total amount of water used to produce a tonne of coal is highly variable (mean of 855 ML/Mt and a coefficient of variation (standard deviation/mean) of >100 per cent. The fresh (raw) water use was 340 ML/Mt with coefficient of variation of 65 per cent. Figure 3 illustrates that there is little relationship between the amount of fresh and worked water used and the amount of coal produced.

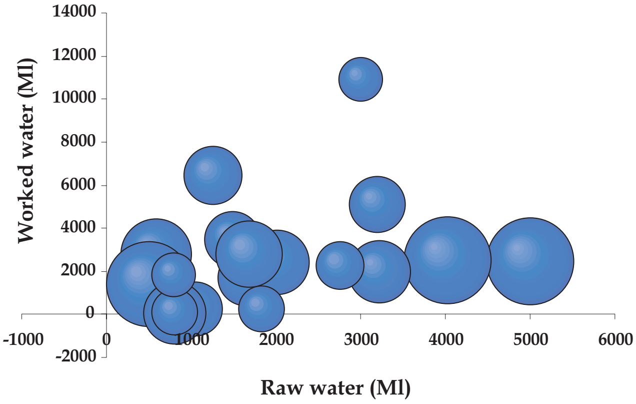


FIG 3 - Estimate of the current relationship between raw and worked water use across a range of mines. The size of the bubbles indicates the coal production.

Table 1 outlines the main areas of water management on Bowen Basin coal mines and the tasks that are undertaken.

The current mining expansion is driven by record coking coal demand to meet the steel needs of China and India. Consequently, prices are at historical highs. Unprecedented demand and prices have coincided with a severe regional drought, which has seen levels in the three most significant water sources, namely, Fairbairn Dam/Bingegang Weir, Eungella Dam and Braeside Borefield, at extremely low levels. Therefore, there have been considerable challenges to meet current coal production demands let alone expansion plans. The need to ensure water security has traditionally been delivered by development of regional water infrastructure. This has continued with the current development of the Gattonvale off-stream storage (to supplement the Eungella Dam system) and the Burdekin Falls pipeline. The latter will deliver ~20 GLpa of high security water to the vicinity of the town of Moranbah and is currently under construction.

Rapid regional development, regional water scarcity and company sustainability priorities mean that securing water for the industry needs to be accomplished with responsible water management principles. There is clear recognition across the industry at site and corporate levels that an organising framework is needed. Such a framework will allow for improved planning, implementation and communication of excellence in water management.

TABLE 1

Main tasks for each of the teams managing water on a coal mine site.

Area	Task
Environment	• Managing storages, roads and drainage to meet licence regulatory requirements; • rehabilitation; • water flow and quality monitoring; • meteorology; and • on-site and surrounding ecosystems management.
Coal handling and processing	• Separation of coal and mineral materials including flotation of the finest coal; • tailings and reject management; • process water return, and • dust suppression and drainage of industrial area.
Mining	• Pit dewatering; • dust suppression on roads, in pits and underground; and • vehicle wash-down.
Corporate	• Sustainable development compliance and reporting; and • formulation and communication of company standard strategies, processes and plans.

Mine site modelling – current situation

In this section the use of a framework for site performance at the technical level of best practice is demonstrated. Seven mine sites were selected for analysis, providing a range of mine types: three open cuts, two mixed underground/open cut and two underground. All underground mines use longwall mining.

An example of model calibration is given in Figure 4, which compares measured water levels of a worked water store and model output for the same period. Site data were as reported in site OPSIM modelling (Water Solutions, 2004). Calibration was achieved by adjusting a single model variable (called the ADELOF factor). This factor describes water that is stored in surface depressions on spoil during rainfall and subsequently evaporates. The importance of accounting for depressional storage for run-off estimation has been known for many years (Hairsine, Moran and Rose, 1998). This is likely to be more

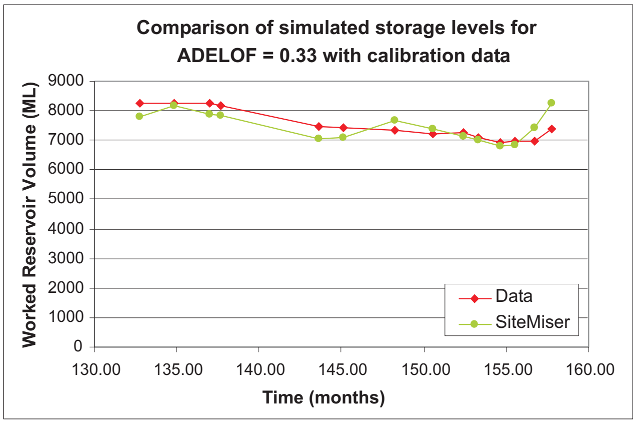


FIG 4 - Modelled and measured worked water store volumes over time.

important than in agriculture because of the large surface roughness and the possibility of storage at a larger spatial scale. The model was also checked against worked water salinity. In this case, time series monitoring data were not available so salinity checking was order of magnitude checking only. Calibration was achieved by adjusting the salinity of run-off water entering the worked water store.

No model calibration was carried out against the salinity of water in the coal preparation plant (CPP). However, the model does estimate this variable. This is, therefore, the strongest validation variable for the model. Clarifier salinity measurements from a single 'snapshot' of each of four mines is shown against the modelled mean in Figure 5.

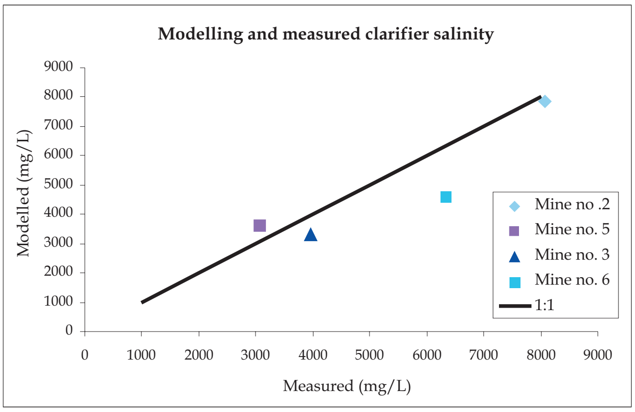


FIG 5 - Comparison of modelled and measured clarifier water salt concentration.

Current water management (current best estimate) at the seven sites was characterised by:

- the volume of fresh water that needs to be imported onto the site for normal mining operations to proceed;
- the storage capacity that is available (both for fresh and worked water);
- the amount of salt that accumulates in the worked water storage; and
- the volumes of water required by each task, and the associated type of water (fresh or worked).

This information is summarised in Table 2, where the volumes of water (ML) used by each task are reported in terms of the mine saleable coal production per annum ML/Mtpa. This describes the productivity of each ML of water used and allows comparison between the various sites.

From the mine site information collated, the following comments can be made regarding current water management at those mine sites:

- There is a wide range of water use, with water productivity varying between 570 and 3000 ML/Mtpa. There would appear to be scope for reducing water consumption at some sites.
- The proportion of fresh water used in the CPP varies from 1.5 per cent to 67 per cent. There would appear to be scope for increasing worked water use in the CPP at some sites.
- There is no obvious relationship between a coal production and water storage capacity, and there is a need to investigate how appropriate the current storage capacities are.
- Losses from reservoirs can be of the same (or greater) order of magnitude as freshwater imports. There would appear to be scope for reducing those losses.
- There is considerable variation in the average salinity of the worked water stores. Most, however, have relatively high salinity. This may cause difficulties if excess water is accumulated because licensed discharges generally carry a concentration limit. Whilst these limits vary by sites, many limits are lower than the salinities report in the table.

TABLE 2

Summary information for seven sites selected for preliminary simulation analysis.

	Unit	Lowest	Highest	Mean
Worked water stores				
Worked water reservoir loss	ML/Mtpa	47	398	219
Worked water storage mean TDS	mg/L	3727	10 103	6503
CPP				
CPP process make-up	ML/Mtpa	296	2839	876
Percentage fresh		1.5	67	25
CPP loss	ML/Mtpa	81	480	202
Dust				
Dust suppression demand	ML/Mtpa	22	214	112
Percentage fresh		0	100	-
Underground				
Underground demand	ML/Mtpa	55	192	128
Percentage fresh		100	100	-
Underground loss	ML/Mtpa	29	180	89
Total water demand	ML/Mtpa	501	2932	1061
Total fresh water demand	ML/Mtpa	134	426	248
Percentage fresh water		15	49	28

The management of the storage of worked water on site is focused on having enough water to meet production needs and not exceeding licence conditions for discharge. The former objective is met by ensuring that the site has sufficient water stocks during dry periods and the latter by having sufficient storage capacity (and pumping capacity to manage it) when conditions are wet.

A simple overall summary indicator for the above objectives is an exceedance curve of filling the available store. Such a curve provides the probability (on the vertical axis) that the volume stored in the reservoir will exceed a certain proportion of the available storage (on the horizontal axis).

Figure 6 shows two synthetic exceedance curves. The brown curve illustrates a site that has a problem with being too dry too often. For example, the store only exceeds 25 per cent full ~15 per cent of the time. The blue curve shows a site with discharge risk, eg the site water storage capacity is 90 per cent full nearly half the time. The 25 per cent full and 90 per cent full indicators for dry and wet, respectively, were chosen because of the likely uncertainty in the simulation input information and the approximate nature of the systems model. It is very likely that at 90 per cent full a store would have a high risk of filling and discharging. The selection of 25 per cent full for a dry indicator is a little more conservative, ie it is not symmetrical with the 90 per cent decision for wet. This is because of additional uncertainty over the depth of pits and the likelihood that the water at the bottom of the store is not likely to be of equal quality to when the store has more water. Near the bottom of the reservoir there is likely to be more sediment, possibly fine coal, additional salt from stratification, possibly more dissolved metals and low pH and low oxygen status. It is desirable to avoid challenging pumping and pipe infrastructure with this water and it is not likely to be attractive for use in coal washing.

To derive storage exceedance curves for the mine sites, the site system model was run with monthly rainfall data for the period 1961 to 2004.

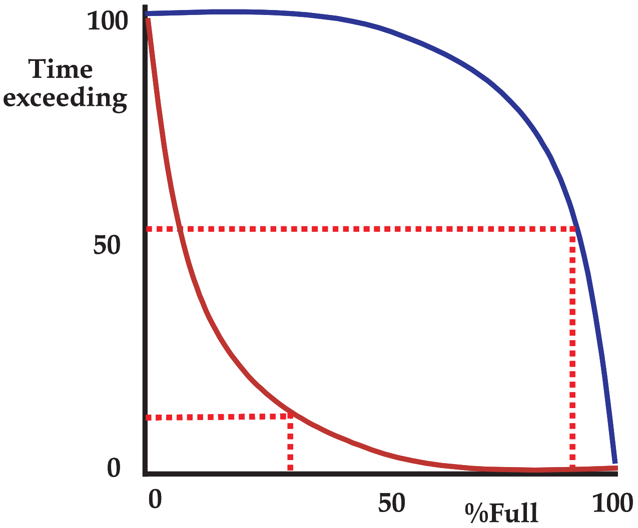


FIG 6 - Synthetic (cartoon) example of site worked water storage exceedance curves.

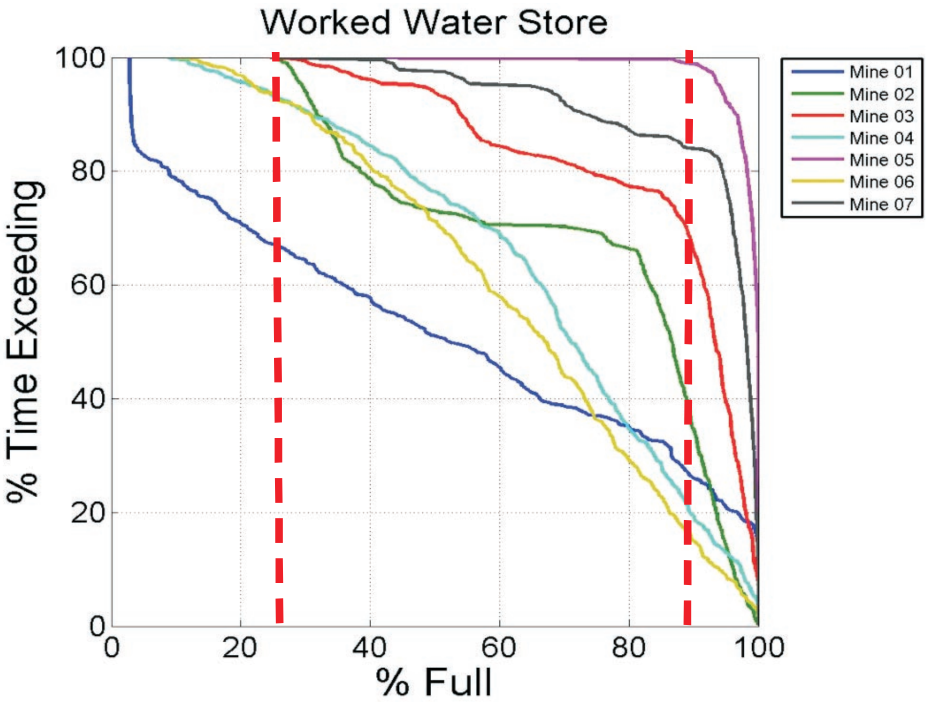
Figure 7 shows the worked water store exceedance curves for the seven sites, along with the wet and dry indicators. One site (mine 1) has a high risk of running out of water, ie, less than 25 per cent full over 33 per cent of the time. Two other sites (mines 4 and 6) also show some risk of running dry. This is not, of itself, a problem if water can be readily imported onto the site to meet production demands. However, if there is pressure on these external water sources the sites become exposed to a risk. This would not appear to be a very sound risk management position in the current conditions in which sources of external water are increasingly difficult to reliably obtain. Unfortunately, there is little that can be done once a site is in a dry situation and external water is unavailable. However, the site could consider increasing its retention of run-off water and/or reducing evaporation and seepage losses to mitigate the problem for future dry periods.

At the wet end, two sites (mines 5 and 7) appear to have a significant likelihood of discharge, ie 90 per cent full >80 per cent of the time. The main management tool required to mitigate this discharge risk is to increase the site worked water storage capacity. This may be a trade-off between cost and maintaining good reputation with the community.

Simulating leading practice

Based on the summary information and the predicted behaviour of worked water stores, a series of water management performance objectives were set (Table 3). These are optimising the worked water storage capacity to avoid discharge of water, minimising the use of fresh water (particularly in the CPP), maintaining sufficient water availability and adopting leading water productivity ratios. Meeting all objectives simultaneously requires an iterative process, where the impact of several practices are simulated and analysed until a satisfactory solution can be found.

Practices relating to the adoption of minimum fresh water use and leading production and loss ratios were imposed on all sites, and several simulations were run with varying values of worked water storage capacity and capture area, until the exceedance curves and associated wet and dry indicators were reasonable. For some sites, 25 per cent evaporation control was also implemented. Table 4 provides the value of the worked water storage capacity and capture areas that were eventually selected and Figure 8 displays the resulting exceedance curves and indicators. Table 5 summarises the water consumption figures and Figure 9 compares the current water management performance with the results derived when trying to meet all objectives.



	Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7
Wet indicator (% time above 90% full)	26	35	66	20	99	15	84
Dry indicator (% time below 25% full)	33	0	0	6	0	6	0

FIG 7 - Worked water store exceedance curves for the seven demonstration sites.

TABLE 3

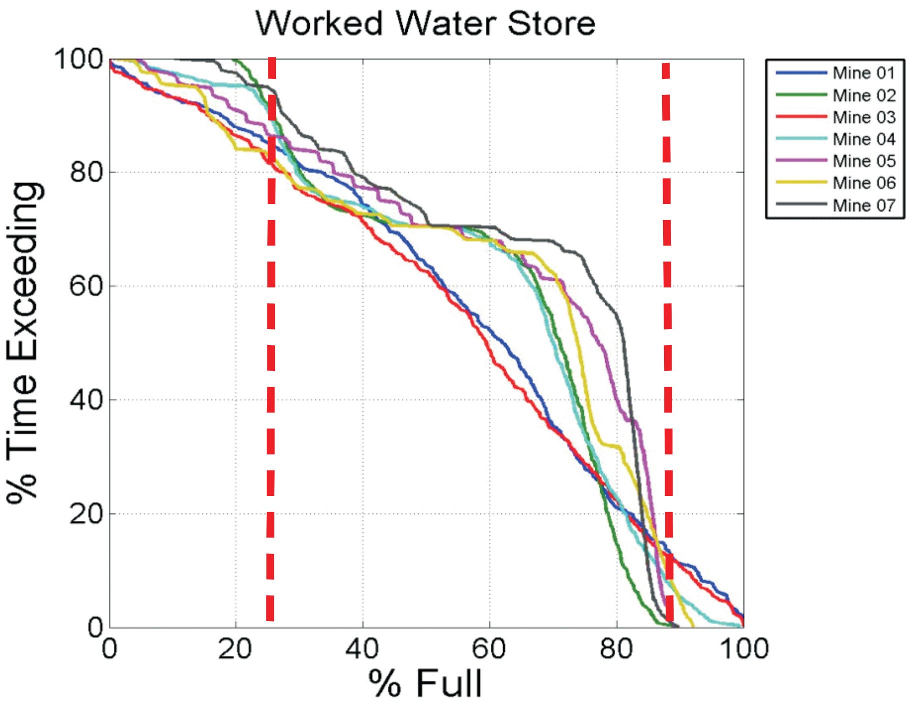
Objectives used by the project team to demonstrate the structured approach to water management. Only examples of technical objectives are shown. The other rows and columns are shown to demonstrate the full proposed framework.

		Conceptual model – system levels		
		Governance	**Surrounding community and environment**	**Site/technical**
Best practice layers	Technical performance	1. Adopt leading practices for water use productivity (ML/Mt) in coal preparation and underground mining.	2. Minimise discharge of worked water. 3. Minimise use of fresh water (the minimum freshwater requirements are potable water, fire fighting and five per cent CHPP make-up for vacuum pumps).	4. There should be no loss of production due to inability to supply fit-for-purpose water.
	Information systems			
	Human systems			
	Plans			

TABLE 4

Practice implementation to meet all set objectives.

		Worked water storage capacity (ML)			**Worked water storage capture area (ha)**			**25% Evap control**
		Current	**Simulated**	**Increase**	**Current**	**Simulated**	**Increase**	
Mine No 1	O/C	226	2750	11X	1683	2104	25%	✓
Mine No 2	M	16 000	17 000	6%	4088	4088	0%	×
Mine No 3	O/C	10 000	10 000	0	6289	9434	50%	✓
Mine No 4	O/C	1600	7000	3.4X	896	896	0%	✓
Mine No 5	U/G	802	34 000	4X	1891	1891	0%	×
Mine No 6	U/G	908	22 750	24X	661	1900	187%	×
Mine No 7	M	16 209	40 000	1.5X	3641	3641	0%	×



	Mine 1	**Mine 2**	**Mine 3**	**Mine 4**	**Mine 5**	**Mine 6**	**Mine 7**
Wet indicator (% time above 90% full)	11	0	11	5	0	5	0
Dry indicator (% time below 25% full)	15	8	18	9	13	17	5

FIG 8 - Worked water store exceedance curves with adoption of practices to meet all set objectives.

TABLE 5

Summary information for seven sites following simulation to meet multiple objectives.

	Largest	**Smallest**	**Mean**
Fresh water demand			
Current production ratio (ML/Mtpa)	325	134	248
Multiple objective production ratio (ML/Mtpa)	70	15	48
Freshwater savings (%)	97	48	76
Worked water demand			
Current production ratio (ML/Mtpa)	2506	290	811
Multiple objective production ratio (ML/Mtpa)	573	303	403
Worked water savings (%)	85	-59	20
Total water savings (%)	87	0	40

After implementation of water management practices to meet multiple objectives, there are obvious relationships between mine type, mine production and proportion of fresh water use in contrast to the current situation (Figure 9), which is somewhat similar to the data for the 21 mines (Figure 3). The mines with the largest production are the mines with the largest water consumption. Mines with underground activities have the larger consumption of fresh water because underground activities do not use worked water.

Two issues arise in assessing the practicality of implementing the practices proposed here.

1. The simulated storage capacities for some sites are very large. There is uncertainty associated with the feasibility of providing such large storages.
2. There is little technical information explaining how the leading production and loss ratios are being achieved. It is therefore hard to assess the difficulty a mine site would face in trying to meet them.

Aspects of water quality were also studied and some results on salt control are reported in Evans and Moran (2006).

CONCLUSIONS

The water balance systems modelling structure introduced in this paper is hierarchical on the basis of complexity of representation and data requirements. Data from engineering model systems were successfully aggregated for systems-level use. More calibration data would be a major benefit.

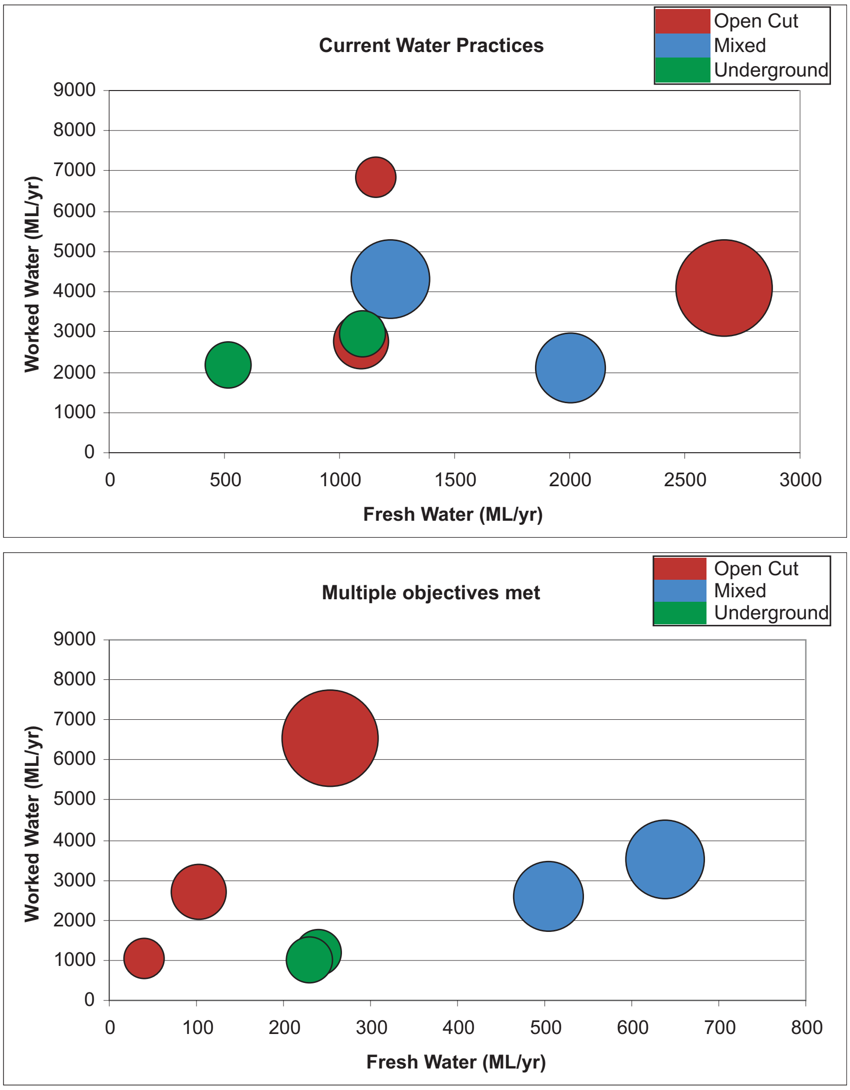


FIG 9 - Relationship between fresh and worked water use for current practices (top) and for all objectives (bottom). Note different fresh water scales.

Mine-level production ratios for 21 mines in the Northern Bowen Basin (ML water/Mt saleable coal production per annum) were shown to be highly variable. The relationship between fresh (raw) water imported onto the site and water reused is not organised with respect to saleable coal production or type of mine.

Water information aligned approximately with areas of water management responsibility on the sites was used to define leading practices. Total water consumed annually could be significantly reduced and dramatic decreases in fresh water importation to sites are, in principle, possible.

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