EVALUATING THE COSTS AND BENEFITS OF MINE SITES SALT MANAGEMENT STRATEGIES USING A SYSTEMS MODEL

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Abstract
Unprecedented expansion in coal mining in Australia is occurring in the context of a severe ongoing drought. This has led more companies to adopt improved water management strategies, such as increased recycling of water. A direct consequence of this is an increase in salt concentration, which can impact on coal quality and equipment maintenance. Salt can be managed by removing it (desalination) or diluting it. A tool is required to predict salt concentrations on mine sites and to simulate the impact of potential management strategies. This paper presents a systems approach to the modelling of coupled mine site water and salt balances to assist with understanding the implications of implementing desalination or dilution and with assessing the costs and benefits of each option.

Introduction
The Bowen Basin (Queensland, Australia) is one of the world's important coking coal mining regions and there are announced growth plans of unprecedented rates. The current mining expansion is driven by record coking coal demand to meet the steel needs of China and India. This demand has coincided with a severe regional drought. There have been considerable challenges to meet current coal production demands and alternative water sources have been sought, such as worked water. Worked water is water that has been involved in a task or has passed over (or through) an area disturbed by the mining processes. It includes water captured from runoff generated over the mine site, groundwater inflows, wash down residuals, and output from the various tasks, such as the water that has been used in a coal preparation plant.

Some of the issues that arise from the increase in worked water use are related to water quality management, and more particularly increases in salt concentration in the worked water. The salt can come from the salty materials that are brought to the surface during open cut mining, thereby producing salty runoff during a rainfall event, or from salty groundwater that is pumped up into the surface water reticulation systems from underground mining operations. As the most important water reuse strategy employed in coal mining is to use worked water to suppress dust on roads and in pits, salt is being left behind when the water evaporates, thereby increasing the potential for yet more salt to be added to the worked water. Salt concentration in the worked water needs to be monitored and managed, as there is strong evidence that using salty water within coal mine sites can have significant impacts:

1. Salt collected in overburden and coarse reject materials can pose a threat to post-closure management of site water dynamics. During operational mining, it is also important to ensure that site water quality discharge limits are not exceeded as a result of run-off from these areas moving off-site into local waterways.
2. Salt present in the water used for coal preparation can compromise coal quality. Negotiations over product price may include consideration of salt concentrations, as it can affect the bulk product itself (purchase of salt instead of coal), it can increase maintenance costs in kilns where salt is combusted, and it can weaken the coke which compromises steel quality further devaluing the coal.
3. There are additional maintenance costs associated with use of salty worked water in coal handling and preparation plants, as outlined by Bartosiewicz and Curcio (2005).

Salt can be managed by accepting and managing the consequences of increased salt concentrations (living with salinity), removing the salt (desalination) or diluting it. For each of these strategies, a tool is required to predict the concentration of the worked water, and to simulate the impact of the management strategies (desalination or dilution) on the concentration of the worked water. Some tools have been developed and are available to study the impact of salt in a mining environment but they tend to deal with the management of salty discharge water or with the fate of salt after a mine has closed. For instance, a study of the long term water quality trends in a post-mining final void was conducted in the Hunter Valley, Australia (Hancock et al., 2005). The model focused on describing the physical processes occurring in the pit and had no connection to mine site water management. With respect to the management of mine waters, several studies have been concerned with alternate ways of disposing of mine water either through irrigation, or treatment and disposal to the environment. For instance, the use of gypsiferous mine water for irrigation of agricultural crops could solve problems related to both shortage of irrigation water and disposal of effluent mine drainage. The long-term effect of irrigation with lime-treated acid mine drainage on soil properties and catchment salt load was investigated with a physically-based soil water, salt balance and crop growth model (Annandale et al., 1999; 2001). Other studies have addressed the issue of salty water being discharged to the environment following desalination, with the treatment process including pretreatment, reverse osmosis, and thermal plant for concentration of brine (Ericsson and Hallmans, 1996; McIntosh and Merritt, 2003; Turek et al., 2005). Except for the McIntosh and Merritt paper (2003), these studies do not address salt management of mine site water during the operational phase.

Whilst there is strong evidence that salt management can be an issue for mine sites, and that it is not restricted to Australia, there is no simple tool for predicting salt concentration in mine waters that could help with assessing potential management strategies for the mine operational phase, rather than the closure phase. This paper demonstrates how a simple systems model can assist with understanding the implications of specific water management strategies on salt balance.

Materials and Methods

A generic model of a mine site was developed to quantify the fluxes of surface water, groundwater and worked water, with salt a constituent of each water flow. The model is a considerably simplified system representation of a mine site. The model 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 (Fig. 1).

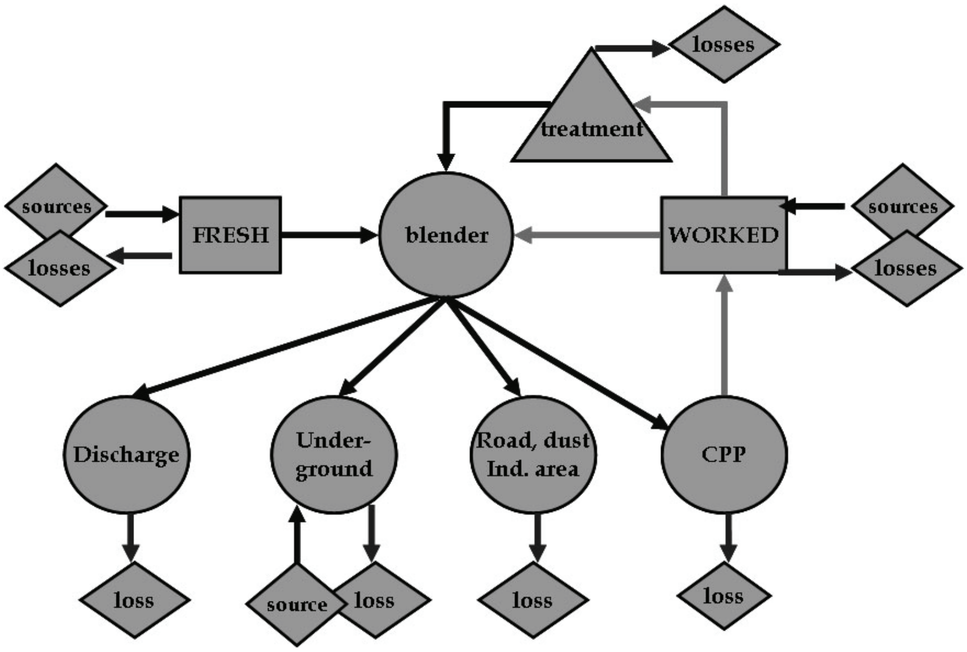

Figure 1. System diagram of a simplified coupled salt and water balance model for a mine site (Moran and Moore, 2005).

Water enters the system as fresh water that is sourced from a pipeline, as aquifer inflows or as rainwater captured on site. Salt 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 is driven for a duration that is determined by the rainfall sequence that is provided.

The model calibration and its performance for representing water flows have been described previously (Moran and Moore, 2005). In other documents (Côte et al., 2006; Moran et al., 2006), the results of applying the model for the comparison of the water balances of seven coal mines in the northern Bowen Basin in Queensland Australia were presented. The model was also checked for prediction of worked water salinity (order of magnitude check 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. However, the model does estimate this variable. This is, therefore, the strongest validation variable for the model. The same 7 example mines (three open cuts, two mixed underground/open cut, and two underground) are used to explore the capacity of the systems model to predict worked water salt concentrations and to simulate salt management strategies.

Results and Discussion

1. Predicting Worked Water Salt Concentration and Deriving Salt Concentration Targets

The previous study (Côte et al., 2006) focused on deriving a series of water management performance objectives, which were: optimising the worked water storage capacity to avoid discharge of water, maximising the use of worked water (particularly in the coal preparation plant), maintaining sufficient water availability, and adopting leading water productivity ratios. The systems model was used to simulate a water management strategy that would meet all of these objectives. The two variables that were analysed to assess salt impacts are: the resulting salt concentration in the water used in the coal preparation plant (referred to as "clarifier water") and the volume of fresh water that was imported on site. Concentration in the clarifier water was selected as variable of interest, rather than worked water concentration, as it enables comparison with a previous study that analysed the relationship between clarifier water salt concentration and annual average maintenance costs associated with salt (Bartosiewicz and Curcio, 2005). Scenario results are summarised in Table 1. As expected, meeting the water management objectives can dramatically increase salt concentration in the clarifier water, and decrease fresh water imports. The magnitude of the change is governed by how close each mine is to meeting the water management objectives.

Table 1. Salt concentration in clarifier water and fresh water import for current situation and optimised water management.

	Clarifier water concentration (mg/L)		Fresh water import (ML/Mtpa)	
	Current	Optimised	Current	Optimised
mine 1	3472	14098	470	199
mine 2	7867	8378	232	168
mine 3	3315	15858	199	20
mine 4	3172	5695	436	23
mine 5	3599	4652	331	77
mine 6	4643	6074	186	98
mine 7	5268	7022	280	71
mean	**4477**	**8825**	**305**	**94**

Anecdotal evidence from mine site visits has indicated that use of saline water for coal preparation has had the consistent impact of reducing the required quantity of flotation reagents (diesel, in particular). Recently, Ofori et al. (2005) have shown the same effect under controlled laboratory conditions. This study showed that about 55% of the benefit could be derived at a concentration of ~5000 ppm, which is reasonable for the mines studied here. A potential salt concentration target would be to set the clarifier water salinity concentration to 5000 ppm. Conversely, preliminary experimental work (Moran et al., 2006) indicated that there is a relationship between salt in fine coal product and salinity concentration of the flotation water. At low salt solution concentrations, salt moves from the coal into the solution, so if the water in the flotation cells is too fresh it is salinised by the coal. When the solution concentration is greater than a coal-specific threshold value, the salt moves from the solution into the coal. The implication in this case is that high concentration solutions will result in more salt in the product. The threshold values for the direction of salt movement for the different coal samples tested were somewhat variable, but for the purposes of demonstration, a salt concentration target of 2500 ppm was selected.

In summary, the salt management targets that were examined were 5000 ppm (to derive flotation benefits) and 2500 ppm (to minimise impacts on coal product quality).

2. Modelling Dilution and Desalination

There are two strategies for reaching the salt concentration targets: dilution and desalination. Dilution is the name given to the process of achieving the necessary concentration limit by blending worked water with the requisite volume of fresh water. The systems model was designed so that a salt tolerance could be set at the water intake to any process. Therefore, worked water is used in a process in so far as it can be diluted with fresh pipeline water to meet the specified tolerance limit. Dilution could then be easily simulated by lowering salt tolerances, so that the maximum salinity of the water entering the CPP is equal to the salt tolerance (2500 ppm or 5000 ppm). The salinity may, of course, be lower if the salinity of the worked water is lower.

For desalination it was assumed that the desalination plant was located between the worked water store and the blender. Therefore, if water was not available to desalinate, fresh pipeline water was used as makeup water. As for dilution, this ensured that water entering the CPP had a maximum salinity equal to the salt tolerance. Again, it may be lower if the worked water is at a lower concentration. In such cases, the desalination plant does not need to be activated and is not. For desalination, it was assumed that 90% of the salt was removed and 10% of the water remains with the separated salt as brine. It was also necessary to select the appropriate desalination plant capacity for each site and for each objective. The capacities were selected by looking at: (1) how often the plant could operate because water was available and sufficiently salty to warrant desalination; and (2) the impact of desalination on the water management objectives outlined above (ensuring the sites did not run out of water nor discharge unreasonably). The full procedure is described for each site in Moran et al. (2006).

The impact of desalination or dilution on fresh water imports are summarised in Table 2. This table does not include additional fresh water supplies such as collected runoff, which, in the model, is used preferentially to water imports. The full fresh water usage, including evaporation from the dam, is greater than summarised here.

It is predicted that some mine sites currently use more fresh water than what could be achieved if they met all water objectives and implemented a salt management strategy.

Table 2. Calculated fresh water imports for current situation, optimised water management, dilution and desalination strategies.

	Fresh water imports (ML/Mtpa)					
	Current	Optimised	Dilution to 2500 ppm	Dilution to 5000 ppm	Desalination to 2500 ppm	Desalination to 5000 ppm
mine 1	140	6	144	134	136	135
mine 2	134	99	268	199	138	134
mine 3	199	20	223	167	155	145
mine 4	432	18	602	264	455	252
mine 5	329	75	568	179	178	179
mine 6	161	73	357	179	197	168
mine 7	279	71	401	313	208	208
mean	**239**	**52**	**366**	**205**	**210**	**174**

3. Comparing Salt Management Strategies

As mentioned in the introduction, using salty water can have direct financial consequences as it can undermine coal quality, thereby reducing its value, and can require additional maintenance costs due to corrosion. One methodology for comparing the simulated scenarios is thus to calculate their cost of implementation and to compare it with the cost of using the untreated salty water. These calculations were based on the cost of water delivery to the site at $1600 per ML; desalination (where applicable) at $1500 per ML; and corrosion cost which is a linear function of salt concentration in the clarifier (Bartosiewicz and Curcio, 2005). Results are summarised in Table 3, with the numbers in bold highlighting which mine can achieve the lowest cost for a specific management strategy (eg. mine no. 3 can implement the water management objectives for the lowest cost) and the numbers in italics highlighting the cheapest option for a specific site (eg. for mine no. 6, dilution or desalination down to 5000 ppm is the cheapest option).

There is considerable variation in the cost efficiencies of the mines currently with the maximum (1.08) being 2.7 times greater than the lowest (0.40). For some sites, meeting the water quantity objectives without implementing salt management strategies is more expensive than implementing salt management strategies. In these cases, the savings from reduced costs for pipeline water have not been sufficient to offset the additional maintenance costs from the increased salinity. The variability of these cost changes illustrates how important it is to take an integrated approach to water quality and quantity management. There is little average cost difference between desalination and dilution. This underscores the potential importance of water price in helping to determine whether water should be purchased for dilution or a technological solution, such as desalination, should be adopted. Desalination, however, uses less freshwater imports and offers the benefits of risk mitigation against regional water scarcity and alternative use of the fresh water, such as community use.

Conclusions

A systems model representing water and salt balances on a mine site was used to assess the advantages of two major salt management strategies: dilution and desalination. The model enables estimation of salt concentration in the mine water and quantification of the fresh water savings that may be achieved with each option. It also provides preliminary design criteria for implementation of a selected strategy (dilution volume, treatment capacity of a desalination plant). Results from the model can be used to derive cost/benefit analyses and guide further technical studies.

Table 3. Estimated costs of water and salt management strategies.

	Cost ($m/Mtpa)					
	Current	Optimised	Dilution to 2500 ppm	Dilution to 5000 ppm	Desalination to 2500 ppm	Desalination to 5000 ppm
mine 1	0.48	1.18	**0.35**	0.43	0.44	0.45
mine 2	0.54	0.51	0.51	***0.50***	0.61	0.56
mine 3	**0.40**	**0.49**	0.41	**0.38**	**0.40**	**0.38**
mine 4	1.08	***0.80***	1.23	0.92	1.23	0.92
mine 5	0.89	***0.61***	1.13	0.76	1.34	0.76
mine 6	0.76	0.80	0.80	***0.75***	0.79	***0.75***
mine 7	0.71	***0.48***	0.75	0.72	0.72	0.71
mean	0.69	0.70	0.74	0.64	0.79	0.65
c.v (%)	35	37	46	32	47	30

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