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An alternative approach to coal mine site water management: a case study on West Cliff Colliery

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Abstract

The provision of water supply, its usage and discharge, are major concerns for all mines, often accounting for a significant portion of the daily running costs. To reduce these costs, mines will collect as much site runoff as possible, and recycle the water whenever economically feasible. The constant recycling of on-site waters can mean that, over time, the levels of salinity, acidity or alkalinity, or other contaminants may build up within the internal water management system to a point which may lead to problems with licensed discharge requirements. This project investigated the water quality at West Cliff Colliery, in order to develop an improved system for managing water resources with minimal environmental impact. While West Cliff Colliery is totally self sufficient and independent of any town water supply, issues have arisen with the quality of water being discharged into the receiving waterways, Brennans Creek and the upper Georges River. To alleviate these issues, a new water management system (WMS) has been established to try and maintain an adequate supply of clean recycled water and to prevent uncontrolled discharges to the environment outside West Cliff's Environment Protection Licence (EPL) requirements. This paper reports on the design of the new WMS, results of monitoring its effectiveness results, and implications for mine operations and environmental licence compliance.

Keywords

alternative, approach, coal, mine, site, water, management, case, study, West, Cliff, Colliery

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AN ALTERNATIVE APPROACH TO COAL MINE SITE WATER MANAGEMENT: A CASE STUDY ON WEST CLIFF COLLIERY

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ABSTRACT

The provision of water supply, its usage and discharge, are major concerns for all mines, often accounting for a significant portion of the daily running costs. To reduce these costs, mines will collect as much site runoff as possible, and recycle the water whenever economically feasible. The constant recycling of on-site waters can mean that, over time, the levels of salinity, acidity or alkalinity, or other contaminants may build up within the internal water management system to a point which may lead to problems with licensed discharge requirements. This project investigated the water quality at West Cliff Colliery, in order to develop an improved system for managing water resources with minimal environmental impact. While West Cliff Colliery is totally self sufficient and independent of any town water supply, issues have arisen with the quality of water being discharged into the receiving waterways, Brennans Creek and the upper Georges River. To alleviate these issues, a new water management system (WMS) has been established to try and maintain an adequate supply of clean recycled water and to prevent uncontrolled discharges to the environment outside West Cliff's Environment Protection Licence (EPL) requirements. This paper reports on the design of the new WMS, results of monitoring its effectiveness results, and implications for mine operations and environmental licence compliance.

WATER MANAGEMENT ISSUES FOR COAL MINES IN THE ILLAWARRA

The constant recycling of mine on-site waters can mean that, over time, the levels of salinity, acidity or alkalinity, or other contaminants may build up within the internal water management system to a point which may lead to problems with licensed discharges. If discharges of waters with certain concentrations of contaminants that, for example, exceed default guideline levels set out in the national water quality guidelines, were to occur, they may well have adverse ecological impacts on the receiving waters.

Mine site waters that are unsuitable for discharge into natural waterways typically carry high concentrations of pollutants, such as, suspended solids, salts, acidity/alkalinity, trace metals, or organic compounds. Acidic waters reflect the formation of sulfuric acid from accessory pyrite in the coal and associated shales (Black and Craw, 2000). Saline waters are a product of the leaching of soluble salts from coal seams, associated shales, igneous dykes and intrusions, and reject emplacements. Coal seams may intersect aquifers and the groundwater in them may contain salts at concentrations in the order of many thousands of mg/L and excessive levels of trace heavy metals. Drainage from waste rock and reject emplacements

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with dispersive fine coal and clay components is the typical cause of high levels of suspended solids (Hounslow, 1995).

All of the coalmines in the Illawarra region have comprehensive Water Management Systems. Management of water is a key colliery process and represents significant economic and time costs in mine operations. There is also a significant issue of control of water quality discharged into the environment through licensed discharge points, which are regulated by the NSW DECC. For these reasons, there is a major interest in new approaches to the management of mine water resources, especially the quality. This will increase the efficiency of water use (reducing the dependence on town water supplies) and to improve the quality of water on site for the benefit of workers, the environment, and to avoid non-compliance discharges. Improving water quality can also dramatically reduce the cost of operations, particularly in underground workings where saline waters reduce the effectiveness of hydraulic chocks, and increase the corrosion of equipment both on the surface and underground. During the processing of raw coal in a coal preparation plant, poor water quality can lead to increased running costs as more chemicals, particularly flocculants and reagents, are required to dose coal feeds as the process water may lie outside the optimum range for these chemicals.

In this paper, water quality at only one mine is discussed, but it is hoped that the information provided can be applied to other locations, leading to improved water quality management.

WATER QUALITY ISSUES

Key water quality issues for mines include salinity, alkalinity and trace metals. Each of these is reviewed briefly below. It is commonly recognised throughout Australia that salinity provides probably the best basis for environmental regulation of flows in freshwater coastal streams and rivers (Bluhdorn and Arthington, 1995; Dept of Water Resources, 1994; Hart, 1992.).

The ANZECC National Water Quality Guidelines (ANZECC and ARMCANZ, 2000) state a default guideline value for electrical conductivity (EC) for NSW upland rivers of 30 – 350 μS/cm and a default guideline value for EC for NSW lowland rivers of 125 – 2200 μS/cm. For all of the creeks flowing from the mines in the Illawarra area, it is unclear as to whether they should be regarded as upland or lowland river systems. This is of concern, as often EC values, which are recorded immediately downstream of the discharge confluences, are above the national default guideline values for a NSW upland river, but may possibly lie within the national default guideline values for NSW lowland rivers.

It is also recognized, and stated in the national water quality guidelines, that default trigger values may be increased or reduced for some ecosystems (ANZECC and ARMCANZ, 2000). This scenario could apply, for example, when it could be shown that there is negligible ecotoxicity at some higher salinity than 300 – 350 μS/cm. Another situation is if the ecotoxicity of a less saline water had been compounded some way by other known chemical factors, e.g., excessively low or high pH values, major concentrations of inorganic species such as the bicarbonate ion (HCO_3^-) (Cowgill and Malazzo, 1991; Hoke *et al*., 1992),

potentially ecotoxic trace elements (Tessier and Turner, 1996), or anthropogenic organic compounds like polymer flocculants used in water treatment (Lamberton, 1995).

With respect to the major ions which are found in regional mine waters of the Illawarra, a comprehensive study of the effects of common salt types on ecotoxicity by Mount *et al.* (1997), noted that their toxicity could be ranked in order $K^+ > HCO_3^- \sim Mg^{2+} > Cl^- > SO_4^{2-}$. Sodium ($Na^+$) and calcium ($Ca^{2+}$) cations were found not to be particularly toxic. Although these major ions are essential and naturally occurring in many water ways, above certain concentrations they become ecotoxic. It is at these ecotoxic levels that Mount *et al.* (1997) ranked them in order of their toxicity. With regard to the waters discharged from coalmines around the region, there is much evidence to suggest that the most ecotoxic major anion is bicarbonate (HCO_3^-) (Cowgill and Malazzo, 1991; Hoke *et al*., 1992; and Mount *et al*., 1997).

Despite the fact that mine discharge waters around the Illawarra are saline, there is little literature available reporting the effects of saline waters on freshwater aquatic biota in the region. Data presented by Mount *et al* (1997), showed that if local mine waters were diluted to the point where the concentration of $NaHCO_3$ was essentially in the range of 600 – 650 mg/L, then ecotoxic effects on the water flea *Ceriodaphnia dubia* should disappear, i.e., a No Observable Effect Concentration (NOEC). This is important as *Ceriodaphnia dubia* is considered one of the most sensitive indicators of aquatic ecotoxicity (Williams et al., 1993; USEPA., 1994) and is the preferred organism of the NSW EPA for the direct toxicity assessment (DTA) of industrial discharges for that reason. A similar NOEC level of salinity for Illawarra regional mine waters (i.e., at ~1000 μS/cm) was also verified by NSW EPA Ecotoxicology Section who could not detect toxicity (either acute or chronic) to the water flea by Elouera Colliery mine water which has an EC of around 1000 μS/cm (reported in Ecoengineers Pty Ltd, 2003).

Jarvis (1997) found minor reductions in the abundance and diversity of macro invertebrates, possibly also indicative of borderline chronic ecotoxicity effects, in the upper Georges River. His site 4a was located approximately 0.6 km downstream of the Bulli to Appin Road Bridge, just below the confluence of Brennans Creek and upper Georges River, which is directly within the influence of any discharges from the Brennans Creek Dam, which discharges treated waste waters from West Cliff Colliery. Jarvis recorded EC values in the range of 309 – 1210 μS/cm at Site 4a and upstream sites above the Georges River/ Brennans Creek confluence in the range of 174 – 325 μS/cm.

For the underground coal mines in the Illawarra, the moderately saline waters, can be attributed to the influence of a carbonate system. This system greatly affects the buffer intensity and neutralizing capacity of the waters (Brownlow, 1996; Langmuir, 1997; and Lottermoser, 2003). The system comprises a series of reactions (Scheme 1):

$$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-} \qquad (1)$$

The reactions affecting the different species are important in ground and surface waters and involve the transfer of carbon among the solid, liquid and gas phases (Lottermoser, 2003). Bicarbonate is the dominant species found in natural waters with a pH greater than 6.3 and less than 10.3; carbonate is dominant at pHs greater than 10.3; and carbonic acid dominates at

pHs below 6.3 (Sherlock *et al*., 1995). Being able to distinguish between these carbonate species is important for the evaluation of mine water chemistry, because bicarbonate is a charged species whereas carbonic acid is uncharged and therefore does not contribute any EC to the water. In addition, dissolved bicarbonate ions consume hydrogen ions providing an acid neutralizing capacity to the water. Therefore the greater the total concentration of bicarbonate species the greater the buffering capacity and alkalinity of the water (Lottermoser, 2003).

Trace elements, which are found in coal mine water discharges, can pose a potential risk to aquatic ecosystems. The trace elements associated with coalmine discharge wastewaters in the Illawarra are generally Cu, Ni, and Zn. Arsenic (As) is also present in low concentrations (White, 2001). It is important to realize, however, that trace elements are present in water in a large number of chemical forms (Stumm and Morgan., 1996) and that not all of these forms are bioavailable or cause ecotoxic effects (Hoffmann *et al*., 1995). Due to the bioavailability of trace elements, the national water quality guidelines explicitly provide for a risk assessment decision tree approach to allow for the consideration of the nature of the chemical speciation of such metals to determine what proportion may be present in the ecotoxic forms (ANZECC & ARMCANZ, 2000).

With respect to As, essentially all of the aqueous species of As are toxic to some degree, and the overall ecotoxicity of As is only modified by the degree to which As exists in the two different redox states –As (III) and As (V). In well oxygenated waters, such as, the receiving waters for mine water discharges, the majority of As would be in the less toxic As (V) state (Ecoengineers Pty Ltd, 2003). For the three major trace metals found in Illawarra mine discharge waters, the ecotoxic species are principally the divalent cationic M^{2+} forms (where M= Cu, Ni or Zn) but also include the less toxic monovalent cationic forms MOH^+ , $MHCO_3^+$, MCl^+ , MF^+ (Tessier and Turner, 1995; Ecoengineers Pty Ltd, 2003).

Speciation modeling of discharged mine water chemistry carried out by Ecoengineers Pty Ltd (2003) using a geochemical model PHREEQC-2 (Parkhurst and Appelo, 1999) showed that the downstream aqueous speciation of Cu, Ni and Zn was noticeably modified by the relatively high salt concentrations in the water with EC in the 1000 – 10,000 µS/cm range. At these concentrations, carbonate, chloride and sulfate were found to complex dissolved Cu, Ni and Zn, so that most of the total concentration was converted into non-toxic neutral and anionic species. Through modeling, it was also found that at higher pHs, total alkalinities and ECs, (ironically in the direction that increases ecotoxic effects due to increased salinity and bicarbonate concentrations) there is a greater complexation of the trace metals reducing their ecotoxicity.

The modeling also showed that the concentrations of ecotoxic Zn species present could possibly be increased at pHs below 8.0 and lower bicarbonate concentrations (Ecoengineers Pty Ltd, 2003). This suggests that the monitoring of Total Alkalinity in mine discharges would be worthwhile as this parameter is important for assessing total bicarbonate concentrations and hence assessing whether Zn is sufficiently complexed by the bicarbonate to significantly reduce its ecotoxic effects. From this modeling, it was also found that the trace elements posing the greatest risk of in-river ecotoxic effects in the Illawarra region were As and Zn.

WATER QUALITY AT WEST CLIFF COLLIERY AND THE RESEARCH QUESTIONS ADDRESSED IN THIS STUDY

This project investigated the water quality at West Cliff Colliery in order to develop improved systems for managing water resources for minimal environmental impact. Details of West Cliff Collieries Water Management System (WMS) are given below. While West Cliff is totally self sufficient and independent of any town water supply, issues have arisen with the quality of water being discharged into the receiving waterways, i.e., Brennans Creek and the upper Georges River. A WMS has been established to maintain an adequate supply of clean recycled water and to prevent discharges to the environment outside West Cliff's Environment Protection Licence requirements. In doing this, a number of questions were addressed:

1. Is it possible to maintain a pH <8.5 for discharges out of the West Cliff mine water Reclaim Pond into Brennans Creek? Maintaining a pH of < 8.5 would ensure compliance with West Cliff's current EPL.
2. Can operating the Brennans Creek Dam in a manner involving water rerouting and new valve control systems achieve a reduction in salinity of discharged waters? Although there is no upper limit in the current West Cliff Colliery EPL for saline discharges, any reduction in salinity will have a positive effect on water quality in the Georges River, as well as improving water quality for on-site use.
3. Is it possible to achieve a target Brennans Creek Dam level of 11 m? At this level, hydrological modelling carried out by Water Solutions (2004) on the Brennans Creek Dam catchment has shown that 90% of rainfall events will be able to be captured equating to approximately 65 ML of fresh rain water.
4. Do the three new approaches described above, specifically the controlling of bottom water discharges through the reclaim pond, increasing freshwater harvesting, and automating the environmental management of discharged excess mine site water, have general application to the design and operation of water management systems elsewhere?

West Cliff Colliery

West Cliff Colliery is the only Illawarra coal mine which is totally self sufficient with regard to its water management system, with little or no reliance on town water. The entire West Cliff Colliery site is located within a 4.8 km² catchment of Brennans Creek, located at 34°14'S and 150°49'E (see Figure 1). The catchment is predominantly covered by a mixture of open sclerophyll woodlands, active and rehabilitated surfaces of coal washery discard, coal and coalwash stockpiles, roadways and aboveground mine site buildings and related infrastructure.

The main purpose of the colliery Water Management System (WMS) at West Cliff is to:

- Recycle contained site waters by catching clean and dirty waters on site;
- Store and clean dirty water runoff in dirty water ponds and tanks, then store as clean water in Brennans Creek Dam (BCD), approximate capacity 320 ML;

- Use recycled water from BCD to directly supply the water needs of the entire site including underground requirements, coal preparation plant (CPP), and bathhouse facilities with a serviceable clean water supply;
- Collect rainfall and groundwater to supply the closed loop system;
- Pump mine water out of the mine workings for cleaning and then recycling via BCD.

The WMS includes a number of drains and ponds, denoted as Ponds 1 to 7 (5, 6 and 7 being very small and not shown in Figure 1), with a total capacity of approximately 100 ML. The ponds are used to store and retain site dirty water, largely coal stockpile and haul road runoff (Ponds 1, Pond 2), site stormwater runoff (Pond 3), and coalwash emplacement seepage (Pond 4).

The coalwash emplacement now occupies much of the upper, southern end of Brennans Creek Valley. Coalwash emplacement (valley filling) in stages 1 and 2 has proceeded over a 28-year period in a northerly direction down the Brennans Creek Valley. Stage 1 has undergone rehabilitation with local soils and revegetation with native plant species.

Immediately downstream of the BCD lies the Reclaim Pond. The Reclaim Pond was built at the foot of the BCD wall in Brennans Creek to catch seepages through the BCD wall and other natural ferruginous groundwater springs. The Reclaim Pond was installed after agreement with the NSW EPA in 1994. The water from the Reclaim Pond is pumped back over the BCD wall, recycling it back into BCD. Below the Reclaim Pond, Brennans Creek runs approximately 520 metres before discharging into the Upper Georges River at a point approximately 1 km to the northeast of Appin.

Study Area and Sampling Sites

The daily testing and monthly sampling sites for the day-to-day monitoring and operation of the study trial were chosen as they represent key areas of West Cliff Colliery's current Water Management System (Volcich, 2007). A site located approximately 50 m upstream of the confluence of Brennans Creek with the Georges River was chosen as a control area, as there is no influence from the West Cliff Colliery mine water discharges (POINT 11).

Specific sampling locations on the West Cliff Colliery site were chosen for the following reasons

POINT (0) is the surface water of the BCD. This area was monitored to give a day-to-day indication of the quality of water at the surface of the BCD. This also allowed for the influences of any freshwater inputs, i.e., rainfall, or dirty water overflows from other settling ponds on site, to be measured as they mixed with the BCD water. The daily temperature and EC readings were used to calculate the density of the surface water.

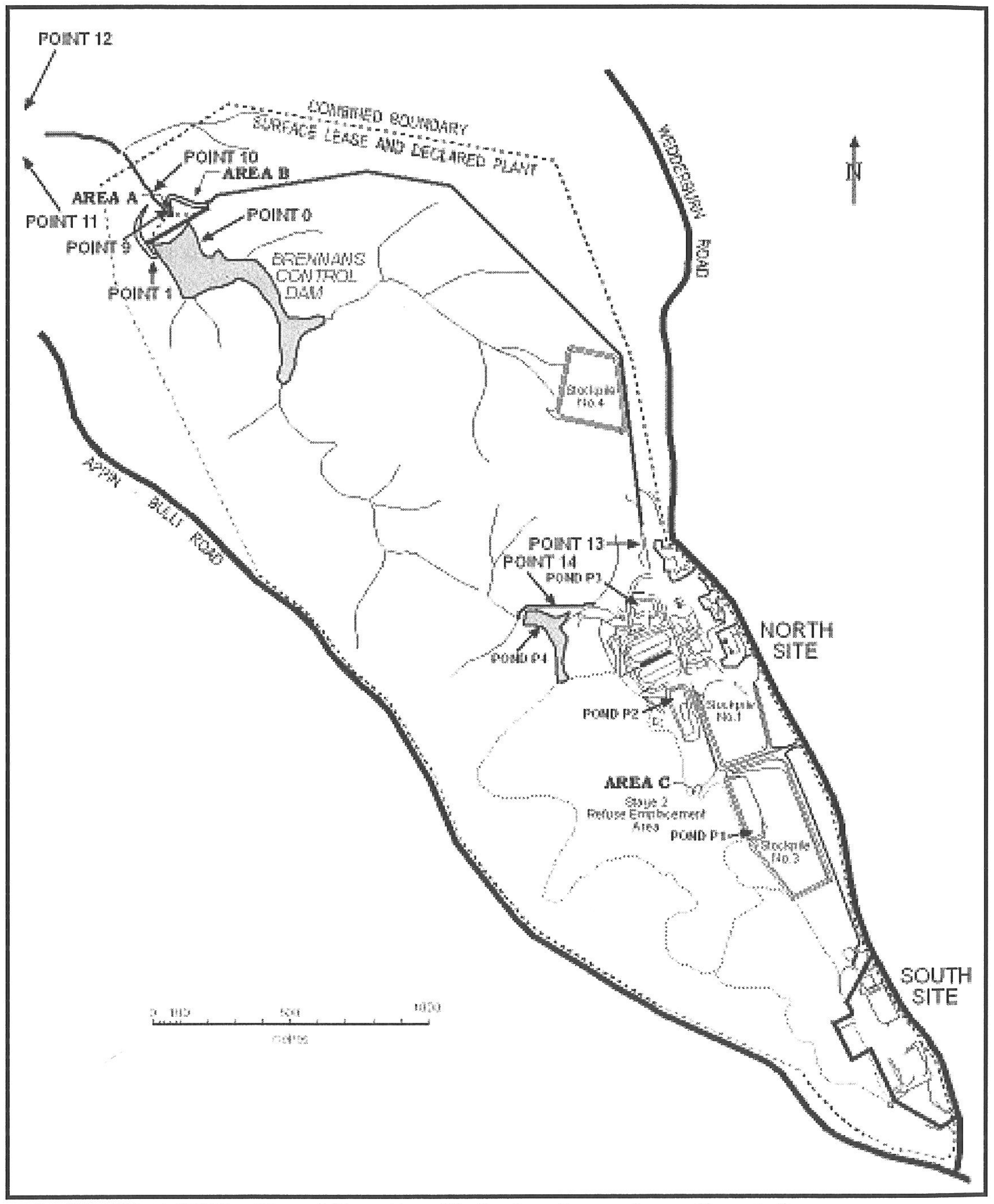

Figure 1. The West Cliff colliery Mine site with the locations of sampling stations.

POINT (1) is the BCD Spillway and EPL# 2504 Licensed Discharge (LDP 1). The spillway was monitored whenever it was flowing as a statutory requirement of the trial and current EPL. When flowing, the spillway also represents an uncontrolled discharge from the West Cliff Colliery Mine Site directly into Brennans Creek.

POINT (9) is the bottom water of the BCD before it enters the Reclaim Pond. This area was monitored to give a day-to-day indication of the quality of water at the bottom of the BCD (12.5 m deep when the water surface is at the spillway). Depending on the quality of the bottom water, releases out of POINT 9 are controlled by the opening or closing of the scour

valve. The daily temperature and EC measurements of this water were also used to calculate its density. Redox measurements were also taken here daily. A flow meter located on the pipe allows the daily discharge volume to be monitored.

POINT (10) is the new LDP into Brennans Creek. Point 10 is located approximately 50 m to the North West of POINT (9). Water coming out of POINT (10) is released from the end of the reclaim pond and is controlled by an on/off butterfly valve. Being released from the end of the reclaim pond means that water from POINT (9), seepages from the dam wall, any rainfall, and a ground water spring can mix together to improve the quality of the water before release into Brennans Creek. A flow meter located at POINT (10) indicates the volume of water that has been directly discharged into Brennans Creek. The difference between the reading on the flow meters at Point (10) and POINT (9) also gives an indication of the amount of ground water and dam seepages into the reclaim pond.

POINT (11) is the sampling area approximately 50 m up stream of the confluence of Brennans Creek and the Georges River. This area is beyond the influence of any water discharges from West Cliff Colliery. It may, however, be influenced by discharges from Appin Colliery, located approximately 700 m up river.

POINT (12) is at the confluence of Brennans Creek and the Georges River.

POINT (13) is where the returning mine water from the underground workings is checked. Water at this site is sampled daily when it is flowing, as it is controlled by a floating offtake valve underground. A flow meter located on this outlet determines the amount of excess mine water returning to the surface. This is done by subtracting the cumulative flow being pumped underground from the cumulative return flow from underground.

POINT (14) is the clean return water into BCD from the washery after treatment in settling tanks to remove oil and grease as well as fine sediments. EC, pH, redox and temperature readings are taken at this site. The EC and temperature readings are used to determine the density of the water to facilitate prediction of how this water will mix with the water in BCD when it enters the dam.

Materials and Methods

The key water quality parameters pH, EC, temperature and Oxidation Reduction Potential (ORP) were measured at the designated sites with probes and meters that had been freshly calibrated each day. Sampling and analysis of water samples collected were conducted using appropriate sample bottles supplied and previously decontaminated by a National Association of Testing Laboratories (NATA) accredited laboratory and supplied with appropriate additives and labelling as prescribed by NATA protocols. Sampling protocols, including the use of field blanks and replicates and analysis methods employed were strictly in accord with New South Wales State guidelines for the sampling and analysis of water pollutants (i.e., ANZECC&ARMCANZ, 2000; DEC NSW, 2004), and with best practice generally in water management in the Australian mining industry

Operation of the Water Management System

In accordance with the water testing techniques and methodology in the previous sections, the WMS was managed by way of manual control of two valves - a scour valve at POINT 9, which could be adjusted to vary the flow coming out of the bottom of BCD and an on/off butterfly valve controlling the discharge through POINT 10 (see Figure 2). The flow out of POINT 9 was controlled such that water being discharged through POINT 10 was below the limits set in West Cliff's EPL. In the event that the water quality being discharged through POINT 10 was above its specified limit, the discharges through POINT 9 and 10 were shut off and the reclaim pump initiated. Water from the Reclaim Pond was then pumped over the dam wall back into BCD. Discharges would also be cut back to a minimal flow of 0.2 to 0.3 ML/day if the water level in BCD fell to 11 m. A small discharge of 0.2 to 0.3 ML/day would maintain a small environmental flow in the Upper Georges River.

RESULTS AND DISCUSSION - POINT 10

From Figures 3 and 4, it can be seen that there was a slow decline in the concentrations of As, Cu, Ni and Zn in the licensed POINT 10 discharge over the course of the 18 months of the trial from August 2004 to February 2006. The arsenic concentration has been reduced by a factor of about 2 from 10 – 13 μg/L to 7 μg/L. The default trigger value for As(V) for protection of 95% of aquatic species in the national water quality guidelines is 13 μg/L (ANZECC & ARMCANZ, 2000). Cu has been reduced by a factor of approximately 2.5 from approximately 18 μg/L to 7 μg/L, well above the default trigger value for Cu for protection of 95% of aquatic species in the national water quality guidelines 1.4 μg/L (ANZECC & ARMCANZ, 2000). Ni has been reduced from approximately 200 μg/L to around 150 μg/L, again above the default trigger value for Ni for protection of 95% of aquatic species in the national water quality guidelines 11 μg/L, (ANZECC & ARMCANZ, 2000). Zn has been reduced from approximately 120 μg/L to approximately 50 μg/L, well above the default trigger value for Zn for protection of 95% of all aquatic species in the national water quality guidelines 8 μg/L, (ANZECC & ARMCANZ, 2000).

Although Cu, Ni and Zn concentrations are above the national water quality guidelines, aqueous geochemical speciation modelling using the United States Geological Survey geochemical model PHREEQC (Parkhurst and Appelo, 1999) showed the concentrations of the ecotoxic cationic species to be 0.0027 μg/L for Cu^{2+}, 0.06 μg/L for Ni^{2+} , and 0.09 for μg/L Zn^{2+}. With pH being in the 8.0 – 8.5 range, all of these ecotoxic cationic species are below the default trigger values for protection of 95%, and in some cases 99%, of all aquatic species in the ANZECC water quality guidelines. These reductions are believed to be a direct result of:

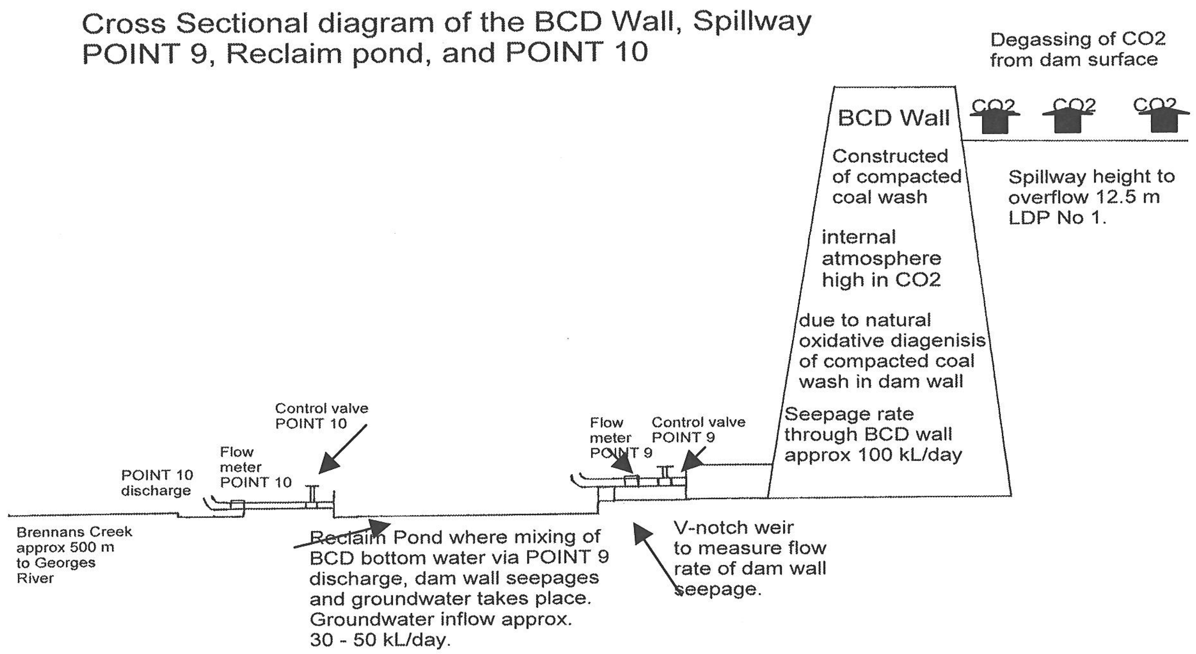

Figure 2. Cross section of the BCD wall and the manual operation of POINTS 9 and 10.

(a) The BCD beginning to progressively capture a higher proportion of the runoff from its catchment area due to the BCD bottom water discharge strategy; and,

(b) Adsorption of As, Cu, Ni and Zn on precipitated Fe and Mn oxyhydroxides, both within the BCD, due to increases in the ORP of bottom waters within the dam (due to improved discharge of reduced bottom waters) and within the Reclaim Pond itself, the Fe and Mn in the latter being sourced from the BCD dam wall and groundwater seepage components.

Continuous pH and Salinity Behaviour of POINT 10

Figure 5 shows the average weekly pH of the POINT 10 licensed discharge monitoring point computed as the average of (usually 10) twice daily readings. It also shows the pH of the occasional spills over the BCD spillway past POINT 1. By combining the inflow of natural groundwater and dam wall seepages into the reclaim pond with the BCD bottom water discharge via POINT 9, the pH of the licensed POINT 10 discharge could then be maintained consistently below the EPL limit of 8.5. This was maintained for close to the entire 18 months from August 04 to February 06. Gaps in the pH data for POINT 10 in mid July 2005 and late October 2005 were due to river rehabilitation work being carried out in the Georges River downstream of its confluence with Brennans Creek. During these two periods, which lasted for 2 weeks each, there was no water released from West Cliff Colliery via the POINT 10 discharge.

From 4 July until 5 August 2005 water was released from POINT 10 at such a rate that the pH was marginally above 8.5 (range 8.5 - 8.9). This was done in order to maximize the rate of fall in the level of BCD and to minimize the pH of water running out of Brennans Creek because over that period:

- the BCD was full and spilling strongly over the spillway past POINT 1 with a much higher pH (range 8.8 - 9.05) than in the bottom water-derived POINT 10 discharge as indicated in Figure 5; and,

- there had been very heavy rain on 1 July 2005 and hence there was substantial runoff in the Upper Georges River catchment to dilute the outflow from the Creek.

Analysis and geochemical modeling conducted on the Reclaim Pond water revealed that the water within the Reclaim Pond comprised about 75 – 80% of BCD bottom water seepages through or around the dam wall, and about 20 – 25% of the water was a low salinity groundwater with chemistry similar to local rain water (Ecoengineers Pty Ltd, pers comm). The modeling showed that most of the Reclaim Pond water that is derived from the BCD became equilibrated along its travel path with an atmosphere containing 0.5-5% by volume carbon dioxide. As the BCD dam wall is constructed largely of compacted coalwash, the atmosphere within the dam wall is enriched with carbon dioxide, due to oxidative diagenesis, a process that occurs continually within coal and coalwash stockpiles. Modeling also showed that the water had become saturated with respect to siderite (ferrous carbonate) and rhodocrosite (manganese carbonate). As these minerals occur together in local coalwash about 7-9% by weight, this also suggests that most of the Reclaim Pond water is derived from seepages through the dam wall.

Consequently, the lower pH values that have been maintained within the Reclaim Pond during this trial, were largely a result of the dissolution of carbon dioxide into seepages from the dam wall that mix with groundwater and BCD bottom water in the Reclaim Pond. The coalwash dam wall material which contains siderite and rhodocrosite also contributes most of the dissolved iron and manganese which is leached out as water from the BCD seeps through the dam wall.

There was considerable catchment runoff captured in BCD during the extended wet period between early October 2004 and early January 2005. It can be seen from Figure 6 that over the first eight months of operation (i.e., until March 2005) the system being trialled had a noticeable effect on reducing the overall salinity (EC) of the BCD (and hence of the WMS as a whole), which is particularly noticeable at POINTS 9 and 10. There was a progressive decline in average BCD EC from around 2875 μS/cm at the beginning of the trial in August 2004 to about 2650 μS/cm by March 2005 equivalent to a reduction in the load of salts circulating within the WMS by about 1% per month. The 8% decline in salinity of POINT 10 over the first eight months of the trial is attributed to the improved capture of rainfall/runoff in the BCD.

However, after March 2005, there was a slow but progressive increase in the average salinity of the BCD. Initially, this was most likely because of a significant fall off in rainfall, with very much lower than average rainfalls through the months of April, May and June. This had the effect of minimizing the diluting effects of runoff entering the BCD and maximizing the concentrating effects of evaporation from both BCD and other water bodies in the catchment as well as maximizing evapotranspiration generally from the vegetated areas of the catchment.

This dry period was punctuated by a short, intense period of rainfall between 24 June and 2 July 2005 when some 139 mm was recorded, including 94 mm on 1 July. This produced a sharp reduction in the salinity of BCD waters in July/August 2005 (Figure 6), but by the end of the trial the average salinity in the BCD had unexpectedly continued to rise, attaining a level around 2975 μS/cm and around 2750 μS/cm at POINT 10. Following further investigation, and noting that rainfall in August continued to be unusually low (maintaining the concentrating effects) the continuing rise in salinity in BCD was attributed to a rise in mine water salinity.

CONCLUSIONS

A trial operation of a modified West Cliff Colliery WMS, based on a novel approach of employing semi-continuous, controlled discharge of bottom waters from Brennans Control Dam has proved relatively successful in meeting its objectives over the 18 months of the trial period from August 2004 through to February 2006 considered here. The trial has continued beyond the period discussed in this paper.

Firstly, this approach ensured that a primary objective of the trial, namely maintaining a pH of <8.5 for discharges out of the Reclaim Pond via (DEC-licensed discharge) POINT 10 into Brennans Creek, was met for almost the entire period considered here without having to resort to the more costly and complex measure of acid dosing. The POINT 10 EPL limit for pH was exceeded only slightly towards the end of the trial from late August 05 to mid September 05.

Secondly, the net salinity load of the salts circulating within the Water Management System over the first 8 months of the trial was reduced by 8% as a result of improved capture of rainfall/runoff into the BCD. Towards the later part of the trial period, in early September 2005, the reduction in net WMS salinity was unable to be sustained due to prolonged dry weather increasing salt concentration around the West Cliff WMS through evapotranspiration, and an unexpected increase in salinity of the mine water being pumped out of the pit to the surface. The trial did show that this was possible given the right conditions and continued operation of the West Cliff WMS in this manner.

Thirdly, the controlled discharge of BCD bottom water through the scour valve at POINT 9 and then through the Reclaim Pond via POINT 10 into Brennans Creek resulted in an estimated reduction of 7 times the total volume of uncontrolled discharges over the BCD spillway for the 18 month trial period. Although the target BCD target level of 11 m was not achieved, it is probable that continual operation of the WMS in the new manner will lead to attainment of the target level. Operating the WMS in the new manner has ultimately ensured that over the trial period from August 2004 through to February 2006, 557 ML of water with the potential of a relatively high pH, high turbidity, and oil and grease contamination, has not been released in an uncontrolled manner directly into the environment. Rather, cleaner water has been released via controlled bottom water discharges through POINT 9 at the bottom of the BCD wall into the reclaim pond where it has been able to mix with BCD wall seepages and natural ground water having the effect of reducing its pH, and salinity to a condition

where it is able to be confidently discharged into Brennans Creek in a controlled manner via the new licensed discharge POINT 10.

The trial has demonstrated that the new strategy of controlled BCD bottom water releases via the new licensed POINT 10 discharge is currently the best practicable means to ensure that over 85% of discharges from the Brennans Creek Catchment are fully controlled with respect to duration and flow rate, and have minimal impact on the Upper Georges River, with respect to pH and salinity.

The new operation of the WMS is also the most cost effective way of managing water discharges into the environment, as it has not been necessary to resort to much more costly and complicated water treatment systems such as acid dosing for pH correction, and reverse osmosis or distillation processes to achieve reductions in the net salinity load of the system. The new operation of the WMS also had the added unexpected bonus of producing reductions in the concentrations of the ecotoxic element As, and potentially ecotoxic elements Cu, Ni, and Zn in the water discharged through POINT 10. These reductions were sustained for the entire period of the trial despite the increased salinity of the discharge waters over the latter part of the period.

This study has shown that it can be practical and economically viable to manage water quality and discharge rates on a large scale at an active mine site by utilising the surrounding environments both natural and man made in unison. Given the right conditions, it has also shown the potential to improve the water quality within the mines WMS, lessening the need to access town water supplies, thus reducing some of the running costs of numerous water consuming aspects of the mining operations onsite. Given the current drought conditions Australia is experiencing, any reduction of the use of potable town water will be of benefit to industry both economically, and in demonstrating its social responsibility to the community.

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