

Study of Waste Water Quality Management in Illawarra Coal Mines

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ABSTRACT

This paper is concerned with two case histories of wastewater quality management in underground coal mines in the Illawarra region. The first investigation briefly presents an analysis of mine water discharge having an extremely high concentration of suspended solids and consistently high barium concentrations, averaging 14.4 mg/l Barium, over the sampling period. A laboratory study of chemical precipitation processes has indicated that about 91% of barium could be removed by using ferric sulphate and lime. On the basis of the information obtained from the environmental audit process an alternative water treatment and reuse system incorporating 51% reduction in the water consumption with 32% less off-site discharge has been suggested (Thomas, 1995).

The second case history is concerned with the storm water management at a mine situated in the Illawarra escarpment where only 20% of the wastewater generated in the colliery is discharged off-site. Computer modelling of the storm water system showed that 75% of the clean runoff becomes contaminated through poor management practices and causes the process wastewater treatment system to fail in wet weather. Suggested improvements include relatively simple alteration to the coal wash filtration dams which are expected to reduce the periods of inefficient operation of these dams by 95%. The use of storm water diversion channels and detention basins can reduce the overflow volumes by 70 - 100 % for a ten year ARI (Average Recurrence Interval) storm event (Wingrove 1996).

INTRODUCTION

Coal mining activities invariably cause environmental problems when contaminated mine water is discharged to environmentally sensitive receiving waters in the Illawarra Region, NSW, Australia. There are 12 coal mines currently in operation in the Southern Coal fields producing approximately 13.35 million tonnes of saleable coal per year. The coal field is the major producer of hard coking coal, which is utilised in the coke ovens in Port Kembla and Whyalla Steelworks and exported to Japan and Europe. Most coal mines in the region are located in the catchment area of the water authority and discharge their effluent to creeks and water courses under licensing conditions imposed by the Environmental Protection Authority (EPA) of New South Wales. In order to meet increasingly stringent water quality guidelines of the EPA and high environmental standards expected by the local community, the mining industry has established a regular program of monitoring and testing mine water effluent. In addition, occasional mine water audits are carried out for characterising the sources of waste water in the colliery and assessing the efficacy of current wastewater treatment processes. Mass balance of water input and discharge from various mining operations and industrial processes are carried out to identify areas of unexplained losses and sources of wastes. The treatment technologies, in plant controls, and wastewater reduction and reuse methods are assessed.

This paper describes research studies concerned with mine water quality management in two mines, one is located in the tablelands about 40 km from the coast and the other located in the escarpment within the Illawarra region.

GENERAL QUALITY OF MINE WATER DISCHARGE IN THE ILLAWARRA COAL MINES

It is known that the mine effluent quality varies significantly from mine to mine in the Illawarra region (Singh 1994,

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Sivakumar et al, 1992, Singh, et al, 1995). The discharge licence conditions also vary from mine to mine depending on the source and receiving waters. The colliery water discharge licence conditions typically require that the selected water quality parameters should be monitored at a minimum of monthly intervals to meet the following conditions:

Five day Biochemical Oxygen Demand	< 20 mg/L
Chemical Oxygen Demand	Not Specified but a target is set at (50 mg/L)
Non-filterable Residue	< 30 mg/L
Grease and Oil	< 10 mg/L
pH	6.5 - 8.5

MINE WATER QUALITY AUDIT - A CASE HISTORY OF MINE A

Site description

The Colliery concerned is situated about 60 km north west of Wollongong where underground mining operations started in 1970. The average coal production from this mine is about 2 million tonnes per annum. The surface facilities at the mine occupy three separate areas as follows:

1. The main site contains the access shaft (No. 3 Shaft), the administration buildings, pit head bath, workshop, washery and coal stockpiles and coal loading and handling facilities. All are situated within a rail loop just west of Sydney-Melbourne main railway line.
2. The reject tips are located east of the rail loop and occupy a large coal refuse disposal area. Because of their size and exposure to weather, the waste stockpiles are prone to water and wind erosion. In the waste tip area, the soil overburden is removed and replaced with the coal refuse from the washery. The waste is then compacted, progressively rehabilitated and revegetated.
3. The No. 2 shaft site is located about 3 km north east of the railway loop.

The water discharged from the mining complex comes from seven major sources as shown in Fig. these being:

1. mine water from three pumps,
2. water from surface amenities and storm water runoff near the office block,
3. surface run-off and storm water runoff from coal stock piles, conveyor belt spray and waste dump area,
4. air compressor,
5. plant wash down bay,
6. gas drainage plant, and
7. water from washery plant and tailings dam.

The site concerned has three EPA (NSW) licenced discharge points. Licence No. 1 is located on the property boundary down stream from the final settlement dam 4. Licence No. 2 is located down stream of the final treatment dam near Shaft No. 2. Licence No. 3 is located at the reject disposal area, adjacent to reject loading bin. In addition to these three licenced discharge points, a non- licenced discharge point is located near the coal stockpile and silt drying area towards the southern side of the railway loop (Singh et al, 1996).

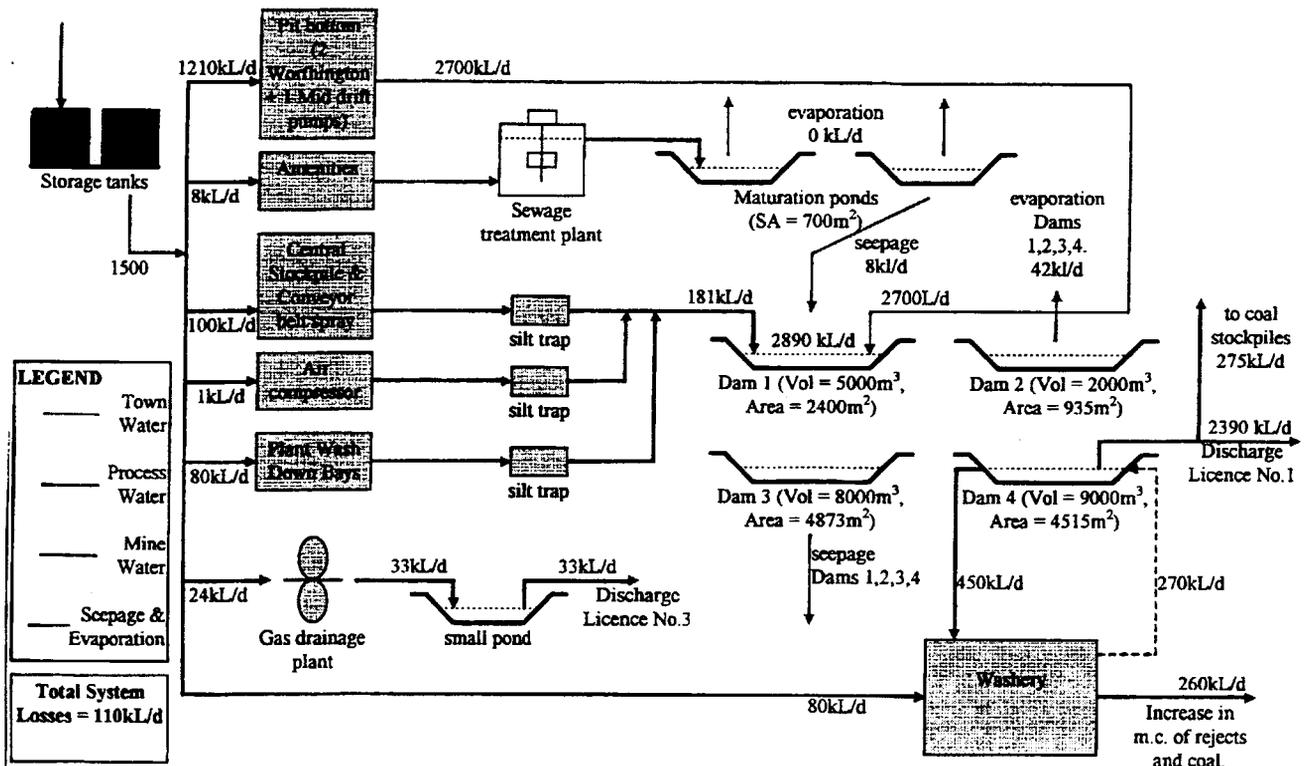


Fig. 1 - Schematic diagram of mine wastewater treatment system at Mine A

Wastewater quality audit

There are 12 water sampling and monitoring points where the water quality is monitored at 3-monthly intervals. The parameters measured are pH, electrical conductivity, non-filterable residue, total dissolved solids and barium. Water quality monitoring at 6-monthly intervals is also carried out at two selected sites (points 3 and 4 in Table 1) where, in addition to the above parameters, BOD concentration and Faecal Coliform counts are monitored. Table 1 shows chemical characteristics of the water from mine A.

Table 1 - Water quality analysis results of the mine site (Thomas, 1995)

Sampling Point	PH	EC □S/cm	NFR (mg/l)	TDS (mg/l)	BOD (mg/l)
1. Town water supply	7.3	156	< 1.0	-	-
		1000-2210	32-48	690-1190	-
3. Sewage treatment plant maturation Dam 1	7.1-8.2	270-500	25-45	184-340	28-54
4. Discharge from maturation Dam 1 to maturation Dam 2	8.9-9.9	370-1220	27-132	228-284	18-85
5. Discharge from conveyor belt spray & central coal Stockpile silt trap	7.5-8.2	254-372	550-1500	173-254	-
6. Discharge from air compressor	6.2-7.3	797-2180	2-12	104-1403	-
7. Washdown effluent	8.8-12	403-1030	702-850	254-820	-
Effluent from Dam 1					-
Effluent from Dam 2	7.3-8.1	878-1427	31-140	311-740	-
10. Effluent from Dam 3	7.6-8.4	638-1452	9-55	397-760	-
11. Washery effluent	8.5-8.7	957-1424	54-196	608-968	-
12. Dam 4 discharge (Licence 1)	7.9-8.5	1015-1441	2-23	550-980	-

Further, a two yearly testing programme is carried out at six selected stations where complete water analysis is conducted including the determination of 32 physical and chemical parameters. The sampling locations are designated as follows :

Mine water	A
Licence discharge 1	B
Creek upstream of licence 1 discharge	C
Creek downstream of licence 1 discharge	D
River upstream of Discharge point	E
River downstream of Discharge point	F

A complete water analysis was necessary to assess the performance of wastewater treatment and general water quality management at the site. These parameters are also required to ensure compliance with discharge requirements under the Clean Waters Act (1970).

A typical result for 1994 is given in Table 2 where the chemical constituents of water are given milli-equivalents per litre and in terms of their cation ratio for different water sources. The cation concentrations of water samples are calculated in milli-equivalents by dividing the concentration in milligram/litre by equivalent weight of the ion under considerations.

The results of these 6 discharge points as shown in Table 2 indicate that B, D and F belong to one group of water, while samples A, C and E to another group with similar chemical characteristics. This indicates that the characteristics of water in the creek and the river are influenced by the Licence 1 discharge. Although mine water in terms of quantity forms a major part of Licence 1 discharge, it shows no resemblance because:

1. Process water has a disproportionate effect on the cation component of the Licence 1 discharge.
2. Cation component of wastewater undergoes changes during retention in the settlement dams for a period of 7 days.
3. Cation component of the mine water is variable.

Table 2 -Wastewater classification at the mine site

Parameters	Mine water meq/l A	Licensed discharge meq/l B	Creek upstream meq/l C	Creek downstream meq/l D	River upstream meq/l E	River downstream meq/l F
Aluminium	0.004	0.015	0.137	0.101	0.036	0.051
Calcium	0.659	1.148	0.085	1.262	0.130	0.379
Copper	< 0.001	< 0.001	< 0.001	<0.001	< 0.001	< 0.001
Magnesium	1.517	0.88	0.214	0.971	0.296	0.485
Sodium	3.349	11.397	0.783	6.873	0.739	3.393
Iron	0.390	0.057	0.036	0.025	0.050	0.043
Manganese	0.050	0.009	< 0.001	0.004	0.003	0.003
Nickel	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Potassium	0.072	0.317	0.087	0.315	0.054	0.118
Zinc	0.002	0.003	0.002	0.002	0.002	0.002
Total Cation	6.043	13.827	1.345	9.554	1.310	4.474
Chloride	4.823	2.426	0.790	0.903	2.200	1.213
Sulphate	0.333	0.25	0.104	0.562	0.042	0.167
Total Anion	8.156	2.676	0.894	1.456	2.242	1.380
Cl/ SO ₄	14.483	9.704	7.596	1.607	52.38	7.263
Mg / (Mg+ Ca)	0.697	0.434	0.716	0.435	0.695	0.510
Sodium/ □Cation	0.525	0.825	0.582	0.719	0.564	0.758

Note: meq/l = milli equivalents per litre

Characteristics of wastewater

Interpretation of the wastewater sampling results in Table 1, and examination of the mine water discharge shows that the mine water exhibits a near neutral pH averaging 6.87 over the sampling period and relatively high conductivity and total dissolved solids (TDS). The conductivity and the TDS levels enable the water to be classified in Class 3, that is characterised the water as highly saline, which can not be used for irrigation on soils that are not freely draining. The suspended solids content (NFR) of the mine water was variable ranging from 39 to 390 mg/l and the suspended solids were usually reddish brown in colour at low concentration and blackish at high concentrations.

The treated discharge from the sewage plant showed near neutral pH averaging 7.5 and low suspended solids content ranging from 25 to 45 mg/l. The discharge had low to medium conductivity and medium total dissolved solids, thus placing it as Class 2, Medium Saline Water. This water is suitable for irrigating soils of moderate draining characteristics. The BOD₅ of the domestic wastewater was slightly higher, ranging from 28 to 54 mg/l, than levels expected for sewage that has undergone secondary treatment.

The discharge from the first maturation pond exhibited a very high mean pH value of 9.4 over the sampling period and low to high suspended solids ranging from 27 to 132 mg/l. The increase in NFR compared to the discharge from the sewage treatment plant can be attributed to the heavy growth of algae in maturation pond 1. Conductivity and TDS levels enabled this discharge to be classified as the Sewage Treatment Plant effluent. The BOD₅ of the effluent is variable ranging from 18 to 85 mg/l.

The pH of wastewater discharged from the conveyor belt and central stockpile was near neutral, ranging from 7.5 to 8.2. The suspended solid content of the wastewater discharge before entering the silt traps was very high, ranging from 55 to 1500 mg/l and consisting of very fine coal particles. The water also had a visible oil slick on the surface and low TDS content, placing it in the Low Salinity category, suitable for irrigation over a range of soils. The salinity of this discharge indicated that the coal fines are not a major contributing factor to the salinity of the wastewater in the colliery.

The wastewater from the machinery wash down bay displayed high pH ranging from 9 to 12. Suspended solids content

were also extremely high (850 mg/l) for discharge exiting from a washdown silt trap. High conductivity and TDS levels characterise this effluent in the class 3 high saline water, which can be used for irrigating only on freely draining soils.

Gas plant discharge was of near neutral pH averaging 6.7 for the sampling period and had very low suspended solid (6 mg/l). Conductivity and TDS contents were moderate to high, placing the wastewater in Class 3, high saline water .

Washery discharge was characterised by a high pH (average 8.6) water, containing very high suspended solids (54-196 mg/l) comprising very fine coal particles. Conductivity and TDS levels were high placing the wastewater in Class 3. The discharge exhibited visible frothing indicating the presence of surfactants (Thomas 1995).

The licence 1 discharge was measured as having a relatively high pH for the sampling period, averaging 8.2 which is within the stipulated colliery's discharge limit of 8.5. Suspended solid levels were low, ranging from 2 to 23 mg/l . Conductivity and TDS levels place the discharge in Class 3 (high salinity water) which is suitable for irrigation of soils with freely draining properties.

Barium investigations

Wastewater discharged from the mine site under investigation displayed high barium contents which could raise the barium levels of receiving river water. The host river for the mine water discharge is rated as Class P (Protected Water) which limits the barium content in the effluent to 1 mg/l. This limit is regularly exceeded by discharges from dam 4 (licence 1) and dam 6, stockpile area. In the period from January 1994 to February 1995, the barium concentration in Dam 4 and Dam 6 discharges averaged at 2.54 mg/l and discharge averaged at 2.81 mg/l. Options of Barium discharge levels in the receiving water are currently under review by the EPA. Table 3 presents a typical result of barium analysis in the mine wastewater circuit in the colliery with a view to isolate the source of barium in the mine water discharge.

Table 3 - Barium analysis results in the mine wastewater (Thomas, 1995)

Sample points	pH	EC (ms/cm)	NFR (mg/l)	Barium (mg/l)
1. Town water	7.10	109	<1	0.14
2. licence 1	8.20	1472	3	3.92
3. Mine water	6.67	974	19	12.24
4. Maturity pond discharge	9.94	458	41	0.09
5. Gas plant discharge	6.38	690	2	1.90
6. Washery discharge	8.54	1424	436	6.00
7. Coal stockpile runoff	8.32	1678	166	2.9
8. Central stockpile drainage	7.55	356	2282	11.60
9. Plant wash down	8.55	506	91	7.91

Source of barium in rock and coal

The amount of barium contamination in the wastewater in the colliery shown in Table 3 is variable which may be derived from a combination of sources. Table 3 also indicates that the largest contributor of barium to the colliery's wastewater is mine water, followed by washery water, plant wash down bay and central stockpile drainage. Pinning down the actual generating point is difficult. If isolation of point source was possible then a strategy of segregation and treatment option could be examined.

It is suggested that the source of barium contamination in mine wastewater might have originated from one of the following sources:

1. Natural rocks surrounding the aquifers;
2. Leachate from coal containing high levels of barium;
3. Oil based drilling fluids containing barytes as a filler; and
4. Lubricants.

A literature review has indicated that barium compounds occur as trace elements in many igneous, sandy and calcareous sedimentary rocks (Bowen, 1979; Swaine, 1990). Most coal contains barium in the form of barytes ($BaSO_4$) and witherite ($BaCO_3$). Those barium compounds found in coal can occur in mineral veins as reported by Forstner and Whittman (1979) in a colliery in Durham, U.K. Table 4 is a compilation of barium levels in selected rocks, naturally occurring water and some Australian coals. Barium content in many soils range from 100 - 1000 mg/kg, however in some geological formation such as fossil fuels much higher levels in excess of 1000 mg/kg have been reported (Bowen, 1979).

Table 4 - Barium contents of various geological materials Adopted from Swaine, 1990; Bowen, 1979; Forstner and Whittman, 1979; and Thomas 1995)

Minerals	Barium (mg/ kg)
Rocks	
Granite Rock	420
Shales	850
Marine clays	2300
Sandstone	320
Limestone	90
Carbonates	10
Basalt	250
Coal	
Latrobe valley, Victoria	60-800
St Vincent Basin, South Australia	220-440
Leigh Creek, South Australia	100-2000
Collie, Western Australia	43-519
Hunter Valley New South Wales	20-1500
Western area, NSW	20-300
Southern Coalfields, NSW	40-100
Site of Investigation	270-630
Sea water	0.013
Fresh Water	0.01

Chemical analysis of coal

An analysis of coal from 3 different locations within the central stockpile on two different dates using Atomic Absorption Spectroscopy has indicated that the coal from this site contains barium between 270-630 mg/kg of coal (Thomas, 1995). Tests carried out by the mine operator on the lubricants used at the site have indicated that the barium level in the oil and lubricants used are not high enough to form a major source of contamination, since the oil spillages are small in comparison to various other sources. However, the moderate to high barium content of the coal and the high barium content in the leachate from the central stockpiles indicate that coal itself may be a major contributor to barium in the colliery's wastewater. It may be observed that ground water travelling in coal aquifers would have the capacity to dissolve barium by ion exchange between ground water and coal stratum over a geological time span.

Physiological effects of barium

The physiological effects of barium on the human body have been studied by the various medical workers including Breenniman and Levy (1985). Australian Drinking Water Guidelines (1994) suggests a limit of 0.7 mg/l of barium in the drinking water. In the majority of Australian water supplies the barium concentration ranges from 0.0005 to 0.3 mg/l. In high concentrations, barium causes constriction of blood vessels, contraction of alimentary canal, convulsion and paralysis. A number of long term studies on the effects of barium on heart disease have shown that no adverse effects were found with barium concentrations in water up to 7 mg/l. In a study using a small number of volunteers, no adverse effects were observed after 12 weeks exposure to drinking water with up to 10 mg/l barium (Brenniman and Levy, 1985).

Barium removal process

Barium can be removed from the wastewater by using one the following processes:

1. Chemical precipitation;
2. Physical adsorption; and
3. Ion exchange.

Thomas (1995) carried out laboratory experiments for removing barium using chemical precipitation method. The results obtained were discussed in relation to other two methods. It was concluded that the most feasible method of reducing barium to below 1 mg/l level in the mine wastewater was the chemical precipitation method, shown in Fig. 2. Chemical precipitation process creates a sludge, which mine operators feel more comfortable in disposing of than dealing with the liquid waste. Other treatment processes, namely ion exchange and reverse osmosis methods have limitations that would require tighter process control during their operations.

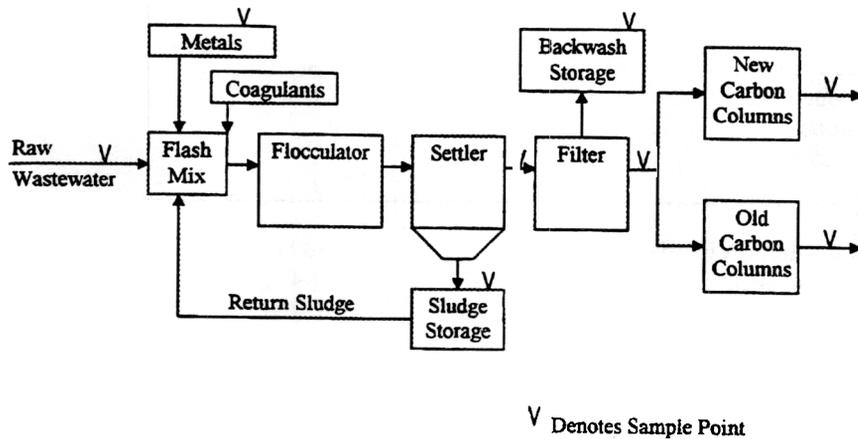


Fig. 2 - Barium removal process using chemical precipitation (Marauyama 1985)

CASE STUDY 2- STORMWATER MANAGEMENT AT MINE B

The second underground coal mine selected for investigation was located in the escarpment area in the Illawarra region and produces some 0.4 Million tonnes of raw coal per year from continuous mining operations in the Wongawilli seam. An on-site washery produces 0.3 Million tonnes of clean coal .

Quantity and quality management of wastewater

The schematic layout of the current wastewater treatment system for Mine B is given in Fig. 3.

System input

The main sources of waste water in the colliery are from (i) mine water discharge, (ii) Washery discharge, (iii) domestic effluent from offices, bath house, loading bays and workshops, and (iv) storm water runoffs. The water requirements for various operations in the mine are given in Table 5.

System treatment components

The main components of the wastewater treatment system comprise a tailings dam, filter dam, an intermediate dam, a settlement dam and the main dam. Wastewater from the surface amenities first goes to a stabilisation pond before discharged into the main dam. A number of sediment traps are built in the wash down bays and the storm water systems before they enter the settlement dam.

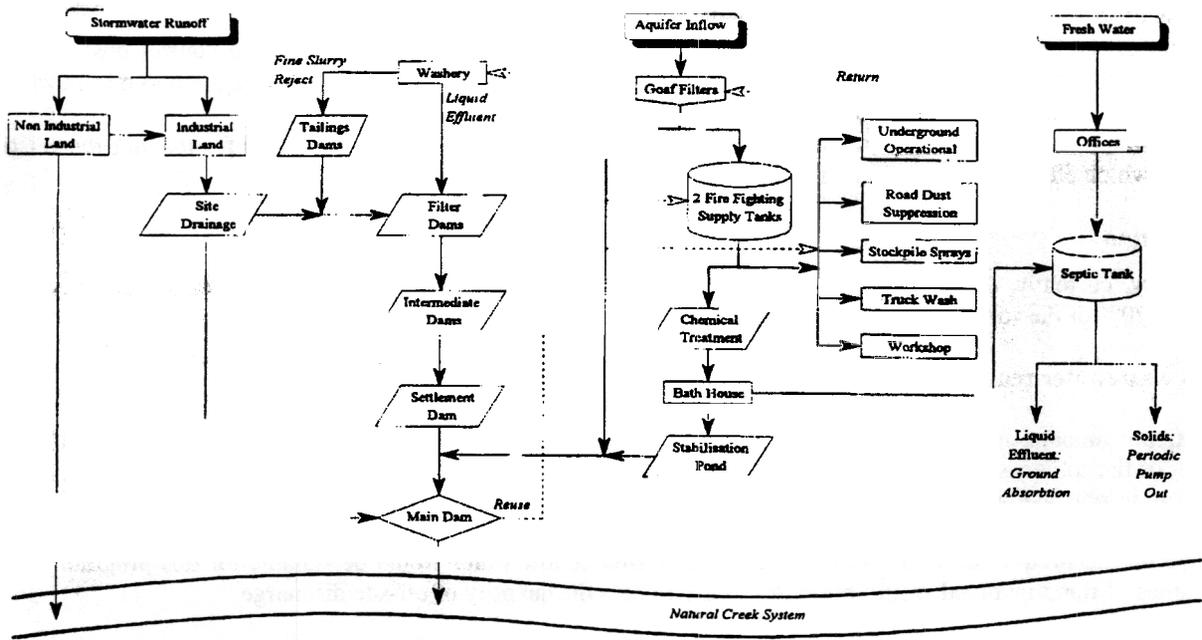


Fig. 3 - Schematic diagram of mine wastewater treatment system at Mine B

Table 5 - Water requirement by the Mine B

Activity	Quantity, m ³ /d	Quality requirements
Office (drinking & kitchen)	0.05	Fresh water
Workshop	1.0	Low NFR, low salts, near neutral
Bathhouse	3.0	Low NFR, low salts, near neutral
Underground operations	200	Low NFR, low salts, near neutral
Washery	1590	Low NFR, near neutral
Stockpile sprays	4.2	Low NFR, near neutral
Truck washing	0.17	Low NFR, near neutral
Road dust suppression	2.5	Low NFR, near neutral
Total	1800.92	

The main sources of wastewater in the colliery are as follows:

- (i) Mine water discharge - The total quantity of water discharged from underground mining operations is 3000 m³/d, which includes 200 m³/d of service water and 2800 m³/d of aquifer water. The main pollutants of the aquifer inflow are dissolved minerals from the aquifers rock strata and non filterable residue (NFR) of 0.4 to 7 mg/l. It is not practicable to prevent the contamination of this water.
- (ii) Bathhouse wastewater - The bathhouse effluent of 3 m³/d is predominantly contaminated by coal fines sticking to the body of the workers and soaps used in their showers. Detergents and disinfectants are also used to clean the bathhouse. This wastewater contains NFR levels ranging from 4 to 157 mg/l.
- (iii) Process (Washery) wastewater - Wastewater from the washery includes 300 m³/d of liquid effluent and the slurry tailings. The liquid effluent is a result of truck washing, machinery and work area wash down and pipe leakages. As such, the wastewater generated, generally consists of a large amounts of NFR in the range of 4000 -13,659 mg/l.

(iv) Tailings dam - The slurry tailings effluent is a waste product from the coal washing process. The colliery currently sells some of these fine "rejects" as a lawn treatment material.

(v) Pit-top operations wastewater - The majority of the pit-top operational water is used to control dust. Methods to reduce the need for using water spraying to control dust include: improving the truck loading system to minimize spillage of coal products and providing windbreaks for large material stockpiles.

vi) Storm water - Storm water runoff from the area surrounding the pit head is responsible for loading the wastewater with NFR which effectively makes water treatment ineffective during storm period.

System output

The colliery, currently, discharges approximately 600 m³/d of treated wastewater from the main dam. This quantity represents 20% of the volume of water removed from the underground.

Process wastewater reuse and disposal

A significant amount of colliery wastewater is already being reused for colliery operations. The aquifer inflow water meets all of the colliery's water needs with the exception of drinking and kitchen (potable) water requirements. For health reasons, it is not appropriate to use the aquifer inflow water for either of these purposes. Thus, the only option for increasing reuse levels at site is for additional non-potable purposes. The colliery rehabilitation program involves extensive revegetation of large areas of land and the aquifer inflow water would be suitable for this program. However, the volumes of water involved would not significantly reduce the quantity of off-site discharge.

Currently the colliery does not specifically make its surplus water available to external industries. The water would be suitable for use by many local industries which do not require water of potable quality for their operations such as:

- irrigation water for local farms, parks, golf courses, green belts or lawns;
- industrial cooling water;
- industrial wash down water ;
- industrial boiler feed water;
- vehicle washing water;
- dust suppression water; and
- industrial and public fire fighting supplies.

The water could be conveyed on-site by pipeline or tanker trucks. Depending on the use, it may or may not be necessary for the water to be neutralised. This option of increasing off-site utilisation of the water is considered to be the most feasible and most significant method of reducing the off-site discharge of wastewater from the colliery. Treatment efficiency achieved at the settling dams is given in Table 6.

Stormwater management

The investigation into the existing stormwater management system at the colliery indicated two main problem areas:

- Hydraulic overloading of the process wastewater treatment dams during storm conditions; and
- Allowance of essentially uncontaminated runoff to become contaminated.

Table 6 - Treatment efficiency achieved in the settling dams

Treatment dam	Effluent NFR concentration
Tailings dams	Decrease by >99%
Filter dams	Decrease by >99%
Intermediate dams	Slight increase
Settlement dams	Slight increase
Main dams	Decrease by > 45%
Stabilisation pond	Increase by >50%

An improved system of stormwater management was, therefore, necessary, with the aim of reducing, or ideally, eliminating these problems. The goals for the improved system are thus to:

- Reduce the pollutant levels in contaminated runoff;
- Reduce the quantity of contaminated runoff;
- Ensure that the quality of colliery discharges is maintained; and
- Ensure that the process water treatment system efficiency is not compromised in storm conditions.

Based on the topography and land uses (Fig. 4) the land use of the colliery is classified into several sub-catchments as shown in Fig. 5. These sub-catchments are grouped together into clean and dirty regions as shown in Table 7. It should be noted that regions C 1 and C2 are separated by a cliff line and C2 and C3 are separated by a ridge line. Similarly, D 1 and D2 are separated by a ridge line. The grouping allows management options to be applied as it is considered more feasible to manage the runoff in regions as opposed to individual sub-catchments.

Table 7 - Stormwater management regions

Region	Runoff quality	Contributing sub-catchments	Comments
C1	Clean	1A, 2A, 4A	Runoff easily diverted
C2	Clean	4B	Runoff easily diverted
C3	Clean	1B, 7B, 9B	Runoff easily diverted
C4	Clean	6A, 7A, 8A	Runoff not easily diverted (drains by gravity to main dam)
D1	Dirty	3A, 5A	Runoff easily diverted
D2	Dirty	2B, 3B	Runoff easily diverted
D3	Dirty	5B, 6B, 8B	Runoff not easily diverted (contains process water treatment dams)

Pollution prevention of stormwater

Many management practices are available to reduce the pollutant levels in runoff. These practices are often inexpensive and relatively simple but can be very effective. Management practices appropriate for the colliery are provided below in the two categories of low and high contamination potential sub-catchments.

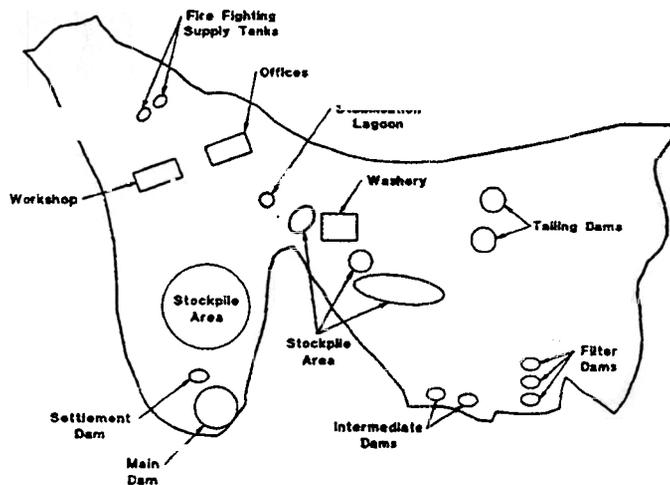


Fig. 4 - Land use and pit-top operations at Mine B

Low contamination sub-catchments

To ensure runoff from low contamination potential areas remains uncontaminated, it is imperative that the flow be diverted away from high contamination areas. This has been discussed (USEPA 1993) and can be achieved through the use of (USEPA, 1993): -

- catch drains;
- interceptor dykes;
- berms;
- open channels; and
- pipelines.

Presently, runoff from area 1A is the only "clean runoff" which is diverted to prevent its contamination. Runoff from this area represents approximately 12% of the total clean runoff volume and 8% of the total runoff volume. If all of the clean runoff were diverted away from high contamination areas, the total volume of contaminated runoff would be reduced by more than 50%. This is a substantial reduction in the quantity of stormwater contamination.

Although considered "clean", runoff from low contamination sub-catchments contains soil particles. The quantity of soil particles picked up by the runoff can be reduced by:

- Increasing the vegetative ground cover. This has additional benefits of absorbing rainfall energy, roots holding soil in place, increasing absorptive capacity of the soil, reducing the runoff velocity as well as acting as a filter to catch sediments. Areas 4A, 4B, 7B and 9B are largely open grassland. The introduction of shrubs and trees is also appropriate.
- Installing straw bale barriers and check dams in diversion channels to decrease the channel flow velocity and thereby allow sediments to settle out of the flow. A reduction of channel flow velocity would also decrease any erosion caused by the flow downstream.

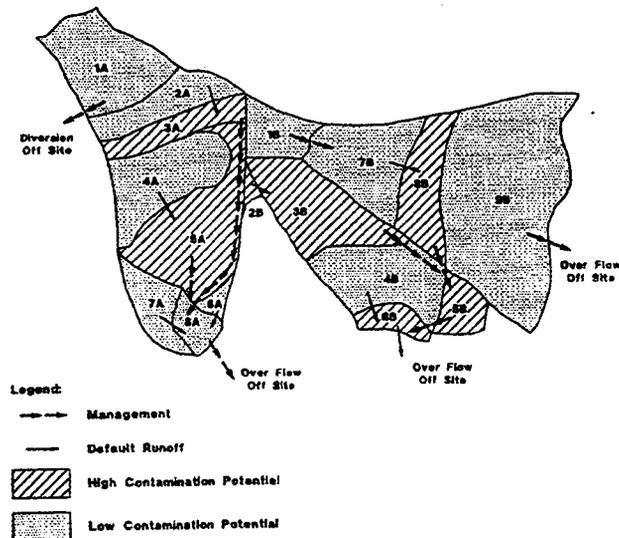


Fig. 5 - Classification of land use and drainage routes for pit top operations

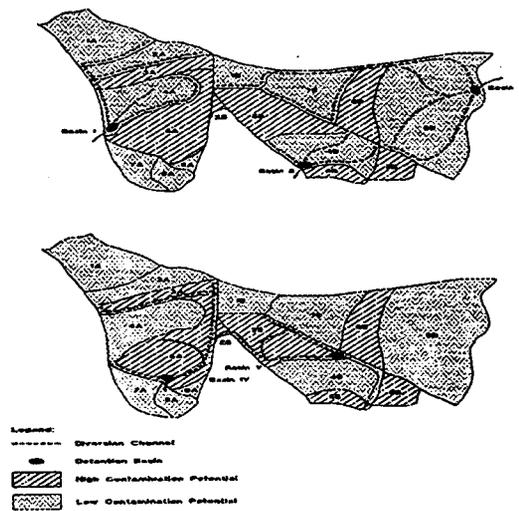


Fig.6 – Conceptual design of storm water management for Mine B

High contamination sub-catchments

The contamination of runoff in these areas can be greatly reduced by minimising the possibility of runoff coming into contact with pollutants. Methods appropriate for the colliery suggested in (USEPA, 1993) include:

- The containment of drips, overflows, leaks or other material releases from vehicles, workshop areas, the washery, and the conveyor belt. This can be achieved through dykes, drip pans and sumps.
- Enclosing material storage areas with curbing barriers to divert runoff around the polluted areas. This is especially suitable for the washery and workshop areas. This can be supplemented by covering the areas to prevent precipitation falling into the curbed area. This however, requires greater capital investment.
- Ensuring trucks are well positioned to minimise spillage of materials during loading and unloading operations.
- Cleaning up or recovering a substance after it has been released or spilled to reduce the potential impact of the spill before it reaches the environment.
- Controlling wind dispersion of particles through the use of water spraying, coverings and wind breaks. The colliery only has water sprays in place on its main coal product stockpile. Additional sprays should be placed on three other substantial material stockpiles which are currently unprotected from the wind. Water spraying has the advantage of confining the pollutants within an area, however it does lead to contamination of that water, which thus requires treatment.
- Trucks operating within the site should be covered in windy conditions.
- The site roads are currently water sprayed daily. It is appropriate for those which carry the heaviest traffic.

A major source of contamination for these areas is the coal product and waste material stockpiles. Due to the size of the stockpiles, methods to minimise the runoff contamination from these areas, such as covering, would be very expensive and thus considered impractical. It is, however, suggested to prevent runoff from other areas entering the stockpile areas. Runoff that discharges from the stockpile areas is highly contaminated by coal fines and should be treated. Similar arguments hold for the process water treatment dam areas.

Stormwater management options

The main aim of managing the clean water runoff is to ensure it remains uncontaminated. In addition, it is desirable to remove the soil loading and control the release of the runoff off site to prevent downstream siltation and flooding. The main aim of managing the dirty water runoff is to ensure it does not compromise the process water treatment system. It is also desirable to remove the coal fines load and control the release of the runoff off site to prevent downstream siltation and flooding. Management options which would achieve, or partially achieve, these goals are outlined in the following in increasing order of complexity and cost (Wingrove, 1996).

- **Option 1** - involves the use of diversion channels to collect clean and dirty stormwater runoff and convey it directly to the natural creek system. The clean and dirty water diversion channels may or may not be combined.
- **Option 2** - involves the use of diversion channels to collect clean and dirty stormwater runoff and convey it to the existing process water sedimentation dams (ie., the intermediate, settlement or main dams).
- **Option 3** - involves the use of diversion channels to collect clean and dirty stormwater runoff and convey it to the process water sedimentation dams, where these dams have been modified to increase their maximum capacity and thus increase their freeboard volume (Table 8).

Table 8 - Freeboard volumes of modified process water treatment dams

Process water treatment dam	Freeboard volume, m ³		
	Existing	Additional feasible	Total
Intermediate dam (east)	600	2,120	2,720
Intermediate dam (west)	800	1,800	2,600
Settlement dam	0	3,000	3,000

Option 4 - involves the use of separate diversion channels to collect clean and dirty stormwater runoff and convey it to purpose-built clean and dirty stormwater detention basins. Lack of suitable land due to topography and heavy capital expenditure requirements precludes this option.

Option 5 - involves the use of separate diversion channels to collect clean and dirty stormwater runoff and convey it to purpose built detention basins. The stormwater is slowly released into holding tanks or dams to store the clarified water for future use.

All of the above options are superior to the existing management method which allows 88% of clean runoff to become contaminated which causes the process water treatment system to fail. The diversion of all runoff away from the process water treatment dams, and in during wet weather particular the filter dams (filter dam walls can collapse and be washed downstream due to overloading) should reduce or eliminate this problem. Of these the most appropriate and cost effective option depends on the volume of runoff that is involved.

Clean stormwater runoff management

This section quantifies the volume of clean stormwater runoff, which is considered capturable and determines the detention times required for the soil particles to be removed from this runoff.

Volume of Diverted Runoff - Ideally, all clean runoff should be captured or diverted. This is somewhat unrealistic due to the topography of the colliery site and the practical locations of diversion channels. The total capturable volume represents approximately 75% of the total volume of runoff from low contamination areas. The total volume of runoff discharged from the four clean regions is summarised in Table 9. Detailed calculations are provided in Wingrove (1996).

Solids Removal - To remove soil particles from stormwater a detention time of 2 hours is typically used (Field et al., 1993). Considering the storm duration modelled and the peak flow rates (Wingrove, 1996) the detention volumes which are estimated to be required for each of the clean regions are summarised in Table 9.

Dirty stormwater management

This section quantifies the volume of dirty stormwater runoff that is considered capturable and determines the detention times required for the coal fines to be removed from this runoff. The quantification is based on the runoff volumes (Wingrove, 1996). Similar to that of clean stormwater management discussed earlier, the capturable volume of the dirty stormwater is summarised in Table 10. The detention time required for each region is summarised in Table 11.

Table 9 – Total discharge volume in low contamination regions

Regions	Contributing Sub-Catchment	Total inflow m ³			Detention volume, m ³		
		Average Recurrence interval			Average Recurrence interval		
		20yr	10yr	5yr	20yr	10yr	5yr
C1	1A, 2A, 4A	17,722	9371	5744	328	762	196
C2	4B	6,342	3356	2061	79	64	48
C3	1B, 7B, 9B	31,634	16,724	10,240	396	317	237
C4	6A, 7A, 9A	10,933	5812	3603	202	162	123

Table 10 – Total discharge volumes in high contamination regions

Regions	Contributing Sub-Catchment	Total inflow m ³			Detention volume, m ³		
		Average Recurrence interval			Average Recurrence interval		
		20yr	10yr	5yr	20yr	10yr	5yr
D1	3A, 5A	17,161	9162	5749	317	256	96
D2	2B, 3B	9003	4835	3064	113	92	71
D3	5B, 6B, 8B	21,724	11,096	6952	272	210	161

Improved stormwater management

A preferred method of management of the clean and dirty stormwater runoff is shown in Fig. 6. This method is selected based on the following assumptions;

- a combination of the five options outlined in a previous section.
- run off volumes for minimum 10 year ARI period
- the topography permits the location of the diversion channels and the detention basins.
- detention volumes are based on a minimum of 2 hour detention time for 10 year ARI storms.

Table 11 - Detention basin design parameters

Influent Region	Basin location	Discharge to	Max. capacity (m ³)	Surface area (m ²)	Avg. depth (m)	Detent. time (hr)			Overflow rate(m/hr)		
						20 yr ARI	10 yr ARI	5 yr ARI	20 yr ARI	10 yr ARI	5 yr ARI
C1	4A	off site	300	200	1.5	1.83	2.29	3.07	0.82	0.65	0.49
C2	4B	off site	80	80	1.0	2.01	2.51	3.35	0.50	0.40	0.30
C3	9B	off site	350	233	1.5	1.77	2.21	2.95	0.85	0.68	0.51
D1	5A	settlement dam	270	180	1.5	1.70	2.11	2.76	0.88	0.71	0.54
D2	3B	intermed. dam	100	100	1.0	1.77	2.18	2.82	0.56	0.46	0.36

Detention basin design

The main design considerations for stormwater detention basins are the detention time and overflow rate. The detention volumes established in Tables 9 and 10 are based on a 2 hour detention time. An appropriate basin volume is adopted using the 10 year ARI detention volume as the minimum design volume. The detention time for each basin is thus greater than 2 hours for the 5 and 10 year ARI storms and slightly less than 2 hours for the 20 year ARI storm. To determine the area and depth of the basins the overflow rate design criteria is used. In this criteria, it is desirable to have

the overflow rate (v_0) of the detention basin to be less than the settling velocity (v_s) of the particles in the stormwater. The settling velocity of the soil particles has been estimated to be 0.98 m/hr. Detailed calculations are provided in Wingrove (1996). The surface areas of the detention basins have been adopted such as to ensure v_0 is less than v_s . Table 11 summarises the features of the suggested detention time. It should be noted that although five new detention basins are suggested to be constructed, the relatively small volume of the basins would result in low construction costs. Construction could be carried out by plant equipment already owned by the colliery. The detention basins which collect the clean stormwater runoff could be omitted and the net effect on the natural creek system would be superior to the effect resulting from the existing stormwater management methods. However, the benefits of detention basins are considered to far outweigh the costs, and thus their use is highly recommended.

Effect on process water treatment system

By implementing the measures outlined above, a substantial quantity of stormwater would be diverted away from the process water treatment dams. This would significantly reduce the hydraulic loading of these dams and thus the wet weather efficiency would approach the dry weather efficiency. Table 12 summarises the percentage reductions of the volume of stormwater discharged into the process water dam sub-catchments and the corresponding reductions in overflow volumes from these sub-catchments.

The following points can be noted from Table 12:

- The overflow volumes from all dams would be substantially reduced by the improved stormwater management.
- The existing method of stormwater management is considered to cause the process water treatment dam to fail. Under the improved method, the process water treatment system would maintain acceptable efficiency for even the 20 year ARI storm.
- For the 5 year ARI storm, there would be *no* overflow from the process water treatment dams.
- For the 10 year ARI storm, there would be *no* overflow from the intermediate dams and the filter dams. The volume of overflow from the main and settlement dams would be reduced by over 70% compared to the overflow which results from the existing management.
- For the 20 year ARI storm, the overflow volume from the filter dams would be reduced by 95% compared to the overflow which results from the existing management. It is particularly important to maintain the treatment efficiency of the filter dams as they play a very significant role in the removal of NFR from the process wastewaters. The overflow volume from the intermediate dams would be reduced by over 70% and the overflow from the main and settlement dams would be reduced by approximately 50%.

Table 12 - Effect of improved stormwater management on process wastewater treatment

Sub-catchment	Process water treatment dams	Increase in process water treatment dams freeboard volume, (%)	Reduction of storm-water discharge into sub-catchment (%)			Reduction of process water treatment dams overflow volumes (%)		
			20 yr ARI	10 yr ARI	5 yr ARI	20 yr ARI	10 yr ARI	5 yr ARI
8A	Main & settlement	43	28	28	27	47	73	100
5B	Filter dams	0	65	65	65	95	100	100
6B	Intermediate dams	280	54	74	-17	71	100	100

The above significant decreases in overflow volumes indicate notably improved wet weather efficiency of the process water treatment system. The corresponding reduced impact on the receiving natural creek environment would also be significant.

CONCLUSIONS

The waste auditing technique provide a powerful tool to assess periodically the efficacy of the mine wastewater treatment

system. This will provide an opportunity to the mine operators to change the mining and processing conditions so that the environmental and economic goals can be achieved. This technique has been successfully applied to a mine site in the Illawarra region where wastewater of dissimilar chemical characteristics could be segregated into separate streams for further treatment.

The wastewater auditing technique has enabled identification of the presence of barium in the mine wastewater. Based on the wastewater monitoring, and the chemical analyses of coal, it has been concluded that the barium in the wastewater is originated from coal. Laboratory assessment of various barium removal options has indicated that the chemical precipitation method is a suitable option for Mine A. The wastewater quality monitoring method has also indicated that the site needs to upgrade its NFR treatment system in case of heavy storm events. A new flow sheet of mine wastewater treatment strategy is developed by Thomas (1995) which allows considerable reuse of water for dust suppression, thus reducing the freshwater consumption by about 50%.

The second case history at Mine B utilised the concept of 'source reduction' to segregate the stormwater into clean and dirty components. The dirty stormwater is then proposed to be diverted using diversion channels and treated with detention basins. These modifications were found to reduce the overflow volumes of the process wastewater treatment dams in 5 year average recurrence interval (ARI) storms by 100%, with reductions of 70% to 100% achievable for a 10 year ARI storm.

Improved process water management systems are also proposed. Relatively simple alterations to the operation of the coal wash filtration dams are expected to reduce the periods of inefficient operation of these dams by 95%. As highlighted in this paper, often there is significant economic benefit resulting from the application of waste minimisation. In addition, there is always a major benefit to the environment.

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