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Coal mine site investigation of wastewater quality in Australia

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ABSTRACT

As the coal industry in Australia continues to grow and expand, there are increasing concerns about its environmental impacts, especially due to water pollution. In order to devise new and effective methodologies in handling and treatment of mine water, a mine site investigation was undertaken in understanding the characteristics of wastewater from coal mines across Queensland (QLD) and New South Wales (NSW). Three representative mines, two from NSW and one mine from QLD, were chosen for the study. Wastewater quality was evaluated from the tests carried out onsite as well from the detailed analysis of various parameters of the water collected from the mine sites. From the mine water survey, it was identified that the major water quality parameters of concern associated with coal mining are salinity, and acidity or alkalinity. In terms of existing treatment procedures, mines generally adopt lime neutralisation and precipitation, flocculation and settling, and membrane filtration. More efficient and cost effective mine wastewater treatment methods are required, so as to maximise the amount of water reused for various onsite purposes and any excess water be safely discharged into the receiving waters. A general overview of conventional wastewater treatment processes adopted by the mining industry was also discussed.

Keywords: Coal mining; Wastewater management; Water quality; Salinity; Mine water reuse

1. Introduction

Coal is Australia's largest export commodity and a major contributor to the national economy. It is the primary fuel for power generation and provides more than 80% of Australia's electricity supply. In 2007–2008, Queensland and New South Wales produced more than 97% of Australia's raw black coal output of 410 million tonnes. In order to support the mining operation, current statistics show that approximately 200 L of fresh water is consumed for every tonne of coal produced, although that can vary both upwards and downwards according to operating practice and circumstances [1,2]. Based on the geographic location, mines in Australia have diverse and extreme climatic conditions ranging from arid to tropical environment, which in turn dictates whether a mine will have too little or too much water. Mines that are water deficit would require external supply of raw water, and where there is excess, water tend to accumulate into mine pits or underground mine workings, local run-offs collected from areas disturbed by mining and coal seams which require drainage for degassing.

Coal mining activities invariably cause environmental problems when contaminated mine water is discharged to environmentally sensitive receiving waters. 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. In 2008, there have been major water quality concerns due

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to large quantities of water discharged from the mines in to the Fitzroy River Basin in Queensland [3]. In the Hunter Valley, NSW, there are many large coal mines operating close to agricultural lands, which depend on Hunter River for irrigation. Increasing salinity in the River over a number of years has prompted NSW Environment Protection Authority (EPA) and NSW Department of Land and Water Conservation to develop Hunter River Salinity Trading Scheme [4]. Another audit conducted by the Department of environment and Conservation NSW, has been reported [5] that in 8 out of 16 mines in NSW, pollution of water has occurred as a consequence of not complying to the discharge conditions specified in the environmental protection licence. The study[3] conducted by the Department of Environment and Resource Management (DERM) found that discharge quality limits and operating requirements for coal mine water discharges are inconsistent, and in the case of some coal mines, do not adequately protect downstream environments. The report's key recommendations include the need to improve the management of waste water in mining activities; reduce the potential for cumulative impacts; and improve water quality data. More recently, in 2009, Department of Environment climate change and water is taking action against a coal mine in Western Coal Fields of NSW for the breach of compliance due to water containing excess sediments from the site causing pollution of Bora Creek and the Goulburn River [6]. Such incidences have caused considerable legislative and community concerns and calls for better management of coal mine water used at the mines. Identifying various sources of water, different usages around the mine site and the water quality of individual water streams within the site is the first step to improve water management on site.

This study reports on the investigation of water quality from three representative mines, two from NSW (Mine A and B) and one mine from QLD (Mine C). Information on water sources was obtained and schematic of water usage and handling was determined. In order to understand the characteristics of various streams, water samples were collected and analysed for key water quality parameters at different locations across the mine sites. Information on the existing treatment methods adopted in these mines is also discussed. This work provides a basis for developing new and cost-effective mine wastewater treatment technologies in the future.

2. Analysis of water samples

The key water quality parameters such as pH, electrical conductivity, temperature and turbidity were measured onsite at designated locations. Turbidity was measured using HACH 2100P turbiditimeter and other parameters using Eutech PCD650 probes. Water samples were collected from representative mines for more detailed water quality analysis in the laboratory. The procedure for all the chemical analysis was carried out according to the 'Standard Methods for Examination of Water and Wastewater' [7].

3. Mine wastewater investigation

3.1. Investigation on Mine A

Mine A is an underground coal mine located in the Hunter Valley, NSW. The schematic of water flow streams is shown in Fig. 1.

Water is pumped from underground inflow sources (U/G 1 and 2) to the surface through the 16 C/T pumping station into Dam 2. It has the pumping capapcity of 3.3 ML/d. Similarly #2 Shaft pumping stations with a capacity of 7 ML/d at 4 bar pressure, extracts water from the underground workings into Dam 1. It is also used as a staging and storage facility. This will also enable Underground water levels in Longwalls to be lowered during normal operations and reduced more rapidly after a major inflow event. Aeration within the storage dams promotes oxidation and assists in the removal of iron and manganese.

Water from the dams is fed into a water treatment plant and treated with lime to raise pH to 8–9 and then flows into a precipitate U-shape Dam to help precipitate any excess lime and metals. Polymer flocculent is added to facilitate the precipitation. The precipitated sludge is periodically removed from the dam and contracted out for disposal offsite. The water is moved to processes water pond for use in coal handling and preperation plant (CHPP) or for further treatment in reverse osmosis (RO) plant. The washery used 2.5 ML/d. Approximately 2.0 ML/d of fine tailings (approximately 15–30% solids) is returned to underground Pelton workings. Water pumped from the process dam undergoes series of pretreatments (before feeding to RO unit) such as primary filtration through standard filters, secondary filtration through multi-media filters and final tertiary filtration through cartridge filters. The RO plant contains 3 units and can treat up to 7.5 ML in total of mine water per day with 3 units running in parallel at 40% efficiency. The current configuration is 2 in parallel with the third used to scavenge additional clean water from the brine of the primary units. This reduces the capacity to treat only 5 ML of mine water per day at 60% efficiency. The brine (approximately 40% of feed water to the RO plant) is returned underground (Bellbird Workings) via the Pollution Control Dam. The clean permeate is used in the CHPP or underground mine with any excess discharged to Bellbird Creek (up to 2 ML/d) in accordance with Environmental Protection Licence (EPL) [8] requirements. In NSW, the discharges from mines are monitored by the NSW Department of Environment, Climate Change & Water (DECCW), formerly known as NSW EPA, and the discharge water quality must comply with the EPL

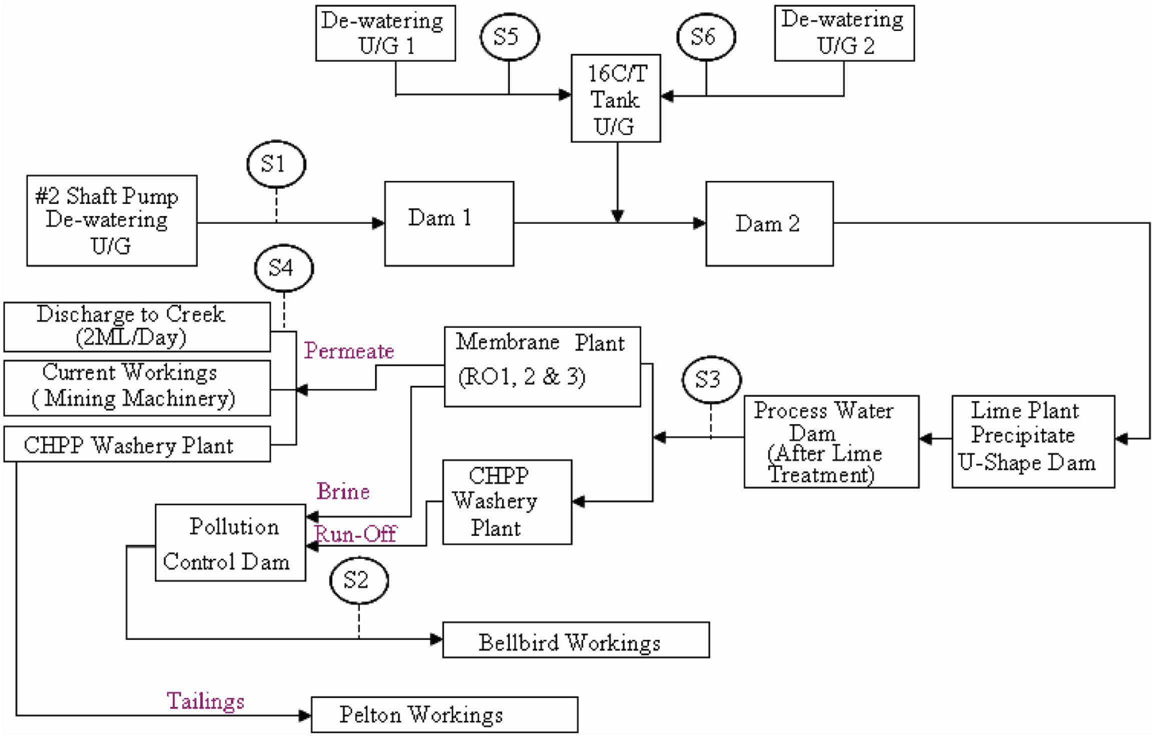

Fig. 1. Process flow diagram for Coal Mine A.

guidelines [8] and the national water qulaity guidelines for receiving fresh and marine waters — Australian and New Zealand Environment Conservation Council (ANZECC) and guidelines [9].

Stormwater management at the CHPP aims to contain all runoff in surface dams up to their capacity with excess dirty water runoff piped into the old underground mine workings via a borehole. All dirty water runoff from the CHPP surface is contained within the dirty water management system, with the final destination in normal operation being the pollution control dam. Water levels in the pollution control dams are monitored and pump status to the underground Bellbird storage borehole checked regularly. In the event of a major storm exceeding the pollution control pond capacity, the overflow from the ponds is directed to the emergency overflow dam. A pump in the emergency overflow dam can return storm water to the dirty water system to minimize the risk of off-site discharge at the licenced outlet of the emergency overflow dam.

Depending on the dam levels, flow rate and demand within the system, water in Mine A is managed via the RO water treatment system, coal washing and handling system, and stormwater runoff and management system.

Six streams have been identified to collect the water sample (Sample S1-S6). These locations represent the property of the water from where it's been pumped from U/G, continuing through the dams, Lime plant, RO plant and finally discharged into the creek or underground. Table 1 shows the results from the water analysis.

The waters collected from Mine A were found to be acidic but generally had no scaling potential (Langelier saturation index, LSI negative). The analysis results indicate that the elelctrical conductivity (EC), total dissolved solids (TDS), ammonia, nitrate and sulphate values are high. The TDS and SO_4 which cannot be removed in the lime precipitation was removed over 98 % in the RO treated permeate. The molar ratio of dissolved inorganic nitrogen (DIN = ammonia + nitrate + nitrite) to dissolved inorganic phophorous (DIP, also reffered to as filetrable reactive phophorus) gives the nutrient dynamics in the water. Ammonia and nitrate concetrations are hign and phophorous concetration was found to be low. Organic concetration (total organic carbon — TOC) including phenol concetration were found to be low. The presence of significant quantities of iron was noticed in Sample 6 where the water is extracted from one of the underground locations.

3.2. Investigation on Mine B

Mine B is an underground coal mine situated near Wollongong in NSW and primarily relies on recycled water for its operation. In 2007–2008, more than 90% of total water usage was recycled water. This mine receives its water from surface runoff and mine water pumped

Table 1
Water quality analysis at different streams in Mine A

Parameter	S1	S2	S3	S4	S5	S6
pH	6.09	3.11	7.15	7.13	4.93	6.82
EC, µS/cm	21000	16000	21000	480	17000	9400
TDS, mg/L	20000	16000	21000	320	18000	7600
Turbidity, NTU	2.02	61.9	6.59	0.16	14.5	154
Ammonia, µg N/L	6459	2597	1296	37	1118	20
Nitrite, µg N/L	13	2	22	2	5	2993
Nitrate, µg N/L	155	170	3548	257	162	14151
DIN:DIP molar ratio	977.0	340.2	151.6	38.5	101.5	2711.1
Bicarbonate alkalinity, mg CO_3/L	< 1	< 1	6	10	< 1	537
Carbonate alkalinity, mg CO_3/L	< 1	< 1	< 1	< 1	< 1	< 1
Total alkalinity, mg CO_3/L	< 1	< 1	< 1	< 1	< 1	< 1
Ca, mg/L	391.0	420.0	480.0	2.6	388.0	271.0
LSI	–5.81	–6.07	–2.74	–2.90	–6.21	1.61
Cl, mg/L	812	661	857	87	893	1050
SO_4, mg/L	13900	10900	14000	77	11700	3620
TOC, mg/L	2.8	4.0	4.1	0.8	2.3	2.4
Phenol, µg/L	< 1	< 1	< 1	< 1	< 1	< 1

from underground mine workings. In order to maximise the amount of recycled water use onsite for the operations and minimise the impact of water discharged to the environment, the two main streams (surface and underground water) are controlled through the Water Management System (WMS). WMS features a Water Treatment Plant (WTP) to chemically assist coagulation, flocculation and settling of mine waters.

All site dirty surface run off from coal stockpile area, haul roads, active coal wash emplacement area and process flows from the coal preparation plant (CPP) is collected and treated to a higher quality in surface ponds, denoted as P1/P2/P3/P4A (Fig. 2). Similarly Underground contaminated water and CPP worked water (discharge) is pumped to concrete settling tanks for chemical dosing and treatment. The site is required to maintain at least 30,000 litres of dosing chemical (Magnasol) on hand at all times to treat a 3 day storm with no deliveries. The settled sediments from the concrete settling tanks are removed periodically to ensure the treatment system operates efficiently.

All water treated by these systems are sent to the col-

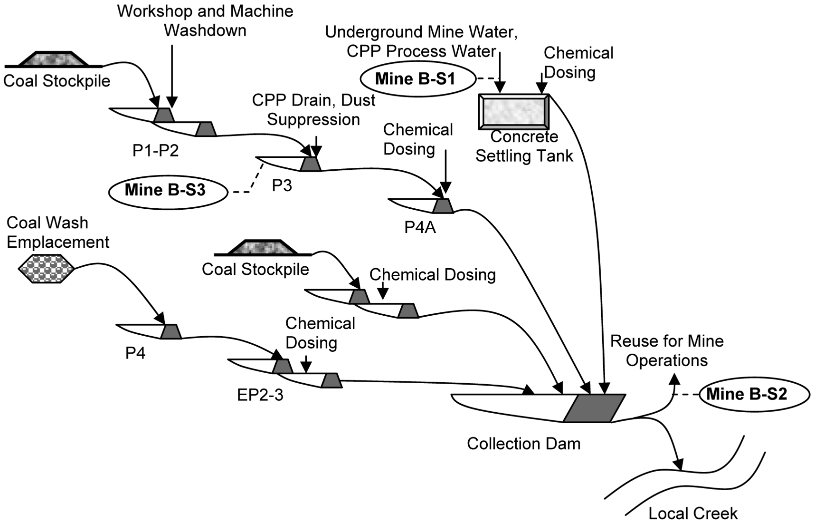

Fig. 2. Schematic of water management system at Mine B.

lection dam, which has a maximum capacity of 315 ML. Water stored in collection dam is reused to supply mining operations including underground mining activity, coal preparation plant, workshop and dust suppression. Excess water on site is being released into a local creek under the Environment Protection Licence, which discharges into the Georges River. Town water is only used in areas that require high quality potable water such as the site bathhouse facilities, associated office amenities and longwall electro hydraulic use.

Three locations as shown in Fig. 2 have been identified to collect the water sample from this mine. These locations represent the property of the water from where it's been pumped from underground and surface ponds, continuing through the treatment plants and finally discharged into the creek or reused. Water analysis results are shown in Table 2.

The nature of the water in this mine was basic and has the tendency for scaling (LSI positive value). Concentrations of nitrate and chloride were high, although some reduction in total N was achieved in the treated water after collection Dam (sample Mine B-S2). High suspended solid and total organic content was noticed in P3 pond, which is located before the chemical dosing point. Both the underground water and the treated water had high levels of bicarbonate alkalinity.

The data of water quality discharged varied with nature of water treatments employed at different mines. For example, most data in S4 in Mine A is lower than that in Mine B-S2. Although, RO treatment provided a better water quality in terms of discharge, the choice of treatment method adopted and its performance contribution must be based on the cost, nature of pollutants present, pollution load and the quality of water requirement for reuse purpose.

3.3. Investigation on Mine C

Mine C is situated near Mackay in Queensland and operate as an underground as well as open pit mining. The schematic of the water management system in this mine is given in Fig. 3

Freshwater for this mine is drawn from the Bowen River that feeds a 100 ML dam. Raw water from the dam together with the water pumped from northern underground borehole is transferred to R5 Portal Underground Workings. The water is then pumped back to the surface and discharges into Ramp 6 or Southern Fill Point. The water from Ramp 6 is fed back to CHPP. CHPP receives water from four places; 100 ML dam, Ramp 8/Ramp1 and Ramp 6 and the southern fill point. All these sources are connected to the Process Pond from where the water is pumped to and from CHPP. Wash down water from CHPP is been fed into a tailings thickener where water is been separated and fed back to CHPP for re-use. The Slurry (15–20% solids) has been pumped to Ramp8/1 where the water seeps through a series of soil piles filtering the tailings out. The water from Ramp8/1 is fed back to CHPP for reuse. The water overflow from the Tailing Thickener is fed back to the Process Pond. The Northern underground de-watering borehole feed Ramp 2 and then Southern Fill point. Water from the Southern fill point is fed back to CHPP for re-use and also used for surface road dust suppression.

Table 2
Water quality analysis at different streams in Mine B

Parameter	Mine B-S1	Mine B-S2	Mine B-S3
pH	8.32	8.9	8.86
EC, µS/cm	5000	3400	3400
TDS, mg/L	3300	2100	2100
Turbidity, NTU	20.9	6.53	340
Ammonia, µg N/L	75	12	2
Nitrite, µg N/L	116	25	6
Nitrate, µg N/L	2368	789	1315
DIN:DIP molar ratio	195.0	114.0	112.0
Bicarbonate alkalinity, mg CO_3/L	1960	1150	1180
Carbonate alkalinity, mg CO_3/L	138	210	160
Total alkalinity, mg CO_3/L	2100	1360	1340
Ca, mg/L	5.1	2.8	3.5
LSI	1.20	1.28	1.17
Cl, mg/L	542	373	393
SO_4, mg/L	22	35	42
TOC, mg/L	8.5	5.8	48.0
Phenol, µg/L	< 1	< 1	< 1

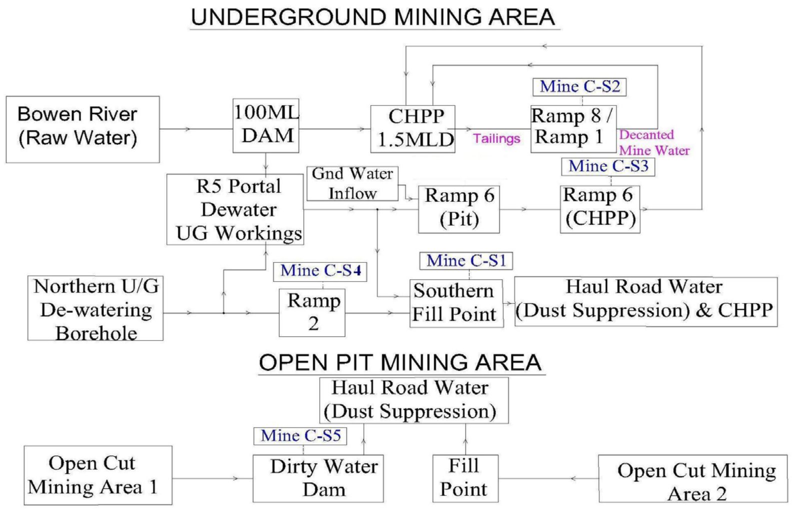

Fig. 3. Schematic of water management system at Mine C.

For the open pit mining area, the water from the open cut mining area 1 fills the dirty water dam. Similarly dirty water is pumped from open cut mining area 2 to an evaporation dam (fill point). Both the dams act as evaporation storage. Dirty water from these dams is used for road dust suppression. Five sample points were chosen for water analysis and the results obtained are given in Table 3.

The water samples collected from Mine C were generally found to be basic in nature. The water from R5 Portal underground workings contained high amount of silica. The problem of scaling was more pronounced for this mine. Although anti-scaling agents were being used, better water treatment solutions are needed to address this problem. Electrical conductivity and TDS increased in the water sample after CHPP operations (Mine C-S2) compared to the feed water (raw and underground water -Mine C-S1). However, the turbidity and the organic content decreased in CHPP water. The open cut mining water was also found to be basic with high scaling potential. Unlike the other two mines, the sulphate concentration was very low in the water samples from this mine. Water high in EC, nitrate and chloride from open cut mining

Table 3
Water quality analysis at different streams in Mine C

Parameter	Mine C-S1	Mine C-S2	Mine C-S3	Mine C-S4	Mine C-S5
pH	8.86	7.79	8.2	8.5	9.6
EC, µS/cm	3700	4128	4432	4457	2765
TDS, mg/L	2300	3000	2800	2600	1500
Turbidity, NTU	6.6	1.37	6.3	8.7	5.36
Ammonia, µg N/L	82	29	30	92	76
Nitrite, µg N/L	2	3	2	2	34
Nitrate, µg N/L	137	138	105	104	304
DIN:DIP molar ratio	32.6	26.9	20.2	33.7	65.4
Bicarbonate alkalinity, mg CO_3/L	350	290	470	392	119
Carbonate alkalinity, mg CO_3/L	61	<1	8	19	103
Total alkalinity, mg CO_3/L	411	290	478	411	222
Ca, mg/L	22.5	164	56	22.8	8.9
LSI	1.46	1.16	1.31	1.06	1.61
Cl, mg/L	714	618	814	1.3	755
SO_4, mg/L	<2	<2	<2	<2	<2
TOC, mg/L	14	2.1	2	3.5	5
Phenol, µg/L	<1	<1	<1	<1	<1

was evaporated in the ponds and the presently used for dust suppression. With further mine expansion plans, better treatment procedures are required.

In QLD, the discharges from mines are monitored by the QLD Department of Environment and Resource Management (DERM), formerly known as QLD EPA, and the discharge water quality must comply with the Queensland Water Qulaity 2006 guidelines [10] and ANZECC 2000 guidelines [9].

3.4. Conventional methods for mine wastewater treatment

Mine waters that are unsuitable for discharge into natural waterways are typically strongly acidic or alkaline and carry high concentrations of salts, trace metals, suspended solids and organic compounds. Mine water treatment technologies can be placed under different categories such as nutralisation of acid, removal of metals, desalination and removal of specific target compounds, as shown in Fig. 4 [11].

Broadly, technologies have focussed on three main areas, namely lime nutralisation, thermal or RO desalination and passive treatment systems. For treating acidic mine waters (acid mine drainage [12]), lime is generally used to neutralise the acid and the metals present in the water are precipitated in the form of metal hydroxides. This process is simple, requires minimal equipment and is usually cheap. Other commonly used chemical reagents are limestone, magnesium hydroxide, soda ash (sodium carbonate), caustic soda (sodium hydroxide) and in some cases ammonia. The main disadvantage in this process is they produce large amount of sludge that require disposal, pH of the treated water needs to be readjusted to neutral values and the process is not selective and require large amount of chemical addition [12,13]. In order to remove suspended solids in water, coagulants (such as inorganic iron and aluminium salts) and flocculants (anionic or cationic synthetic polymers) are often used. Two main desalination technologies often used are thermal and membrane (RO) processes. In a scoping study of various affordable desalination technologies to treat typical saline water produced by the coal industry, electrodialysis reversal (EDR) was found to be the most prospective technique. EDR outperforms RO where a high water recovery (up to 95%) is a key issue or when there is a difficult feed water condition (e.g. high in silica) where membrane fouling and chemical cleaning would be a burden in the case of RO process. Although desalination processes are very expensive, due to drop in the cost of membranes the cost of desalination has actually halved in the last five years but still not below the target value of $A500/ML [14,15]. Biological treatment of mine water consists of passing wastewater through a series of shallow, artificial wetland systems or tanks containing specific bacteria where biological activity can help reduce pollutants in the wastewater. The most common passive treatment systems are sulphate reducing bacteria-based processes, anoxic limestone drains, constructed anaerobic

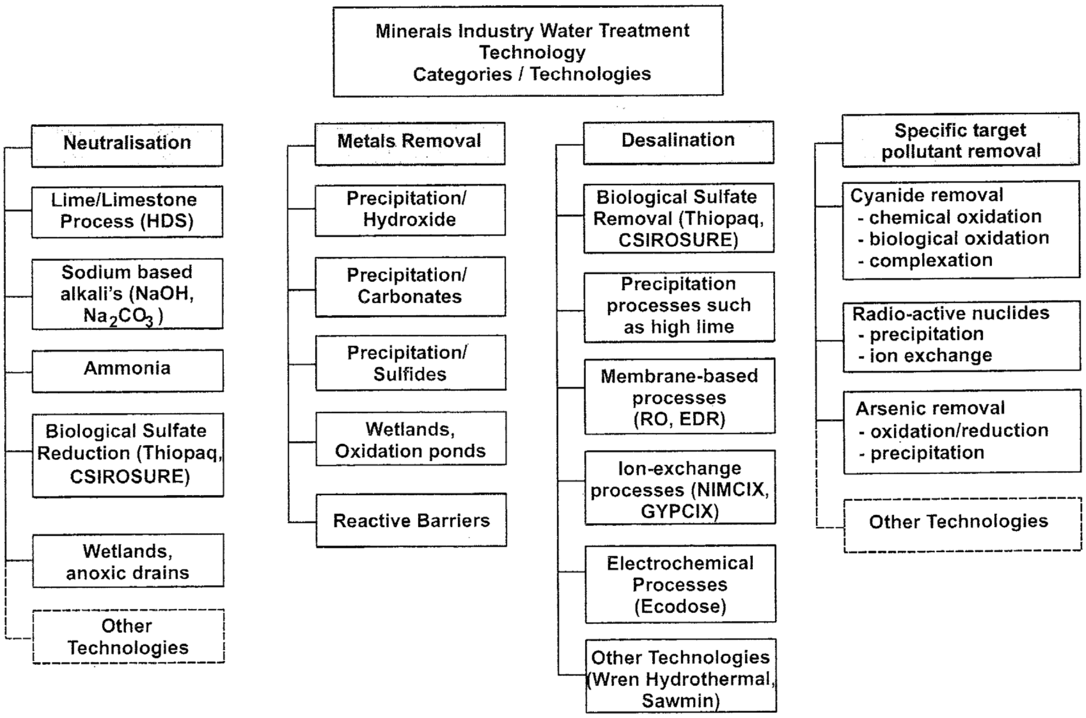

Fig. 4. Conventional mine water treatment technologies [11].

and aerobic wetlands and biosorption [16]. An appropriate treatment process for a given site is selected based on the quality and quantity of the mining water, type of parameters that require removal/reduction, treated water quality objectives and capital and operating costs.

4. Conclusions

Mine waters investigated from three different coal mines (underground and open cut) from QLD and NSW showed significant variation in qualities from being basic to acidic in nature. Waters from Mine A and C had high scaling potential, whereas water from Mine B was acidic. Some mine effluents waters had high alkalinity levels. Common feature in all these mine waters is they are high in EC and TDS. Water from Mine A had significant amounts of sulphate. High amount of iron from underground water from this mine, was also evident. However, more detailed analysis of heavy metal compositions is required.

Mining operations from these mines (especially Mine A and C) could contribute to pollutant loadings of near-by water bodies. There is a strong need to improve their mine water and mine effluents by adopting better treatment and management practices. As in the case Mine A, there is potential for recovery of value added resources as well.

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