What happens to the stream when the coal mine closes – A cautionary tale for legislation, licencing and best practice

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Key Points

- Discharge water from closed mines continue to pollute the waterways of the Greater Sydney Region
- Discharge water increases salinity, metals; modifies temperature, pH and ionic composition
- Discharge adversely impacts macroinvertebrate richness and abundance
- Currently operating mines provide insight into how these mines leave a legacy of pollution
- Licencing based on ANZECC guidelines doesn't necessarily equate to reductions in pollution
- Protection of these watercourses starts prior to development consent through careful analysis of geochemical composition of the coal seam and receiving waters, groundwater hydraulics, water treatment methods and water extraction/management
- Legislation surrounding approval and operation must consider all these parameters, leading to site-specific best practice during mine operation and closure

Abstract

Coal mining has played an important social and economic role in Australia since mining commenced in 1860. Early coal mining activities extending to the mid-20th century had few environmental protections despite an understanding of acid mine drainage and its impact on waterways. Even with the introduction of environmental legislation and pollution licencing in the 1970's, many active and closed mines have inadequate environmental licences and controls. Regulation of coal mine wastewater has focused on a selected suite of analytes at the point of discharge. Naturally acidic streams, common in the Sydney basin, receive buffered alkaline mine water that meet the pH limits and metal concentrations of their environmental pollution licences. Remobilisation of metal contaminants as water returns to its naturally acidic state is occurring downstream of many current and former coal mines. This creates both longitudinal and temporal environmental problems. We use case studies to highlight current and emerging environmental issues within naturally acidic streams due to licenced and approved coal mine wastewater discharge. Our iterative discovery of the environmental impacts of coal mine wastewater provides a critique of current mining and regulatory practice. Primarily, the research is to forewarn environmental legacy issues of coal mining that may present multi-generational impacts if not managed within the mine planning, operation, licencing, and eventual closure.

Keywords

Pollution licencing, coal mine wastewater, contamination, water chemistry, legacy mines, mining legislation, mine closure, acid mine drainage.

Introduction

Coal mining is a major economic activity in NSW, producing 246.8 million tonnes of raw coal in 2015/16 (NSW Department of Industry, 2017). Coal mining has occurred over the past 150 years in the Greater Sydney Region, primarily via underground mining. Underground mining produces significant volumes of wastewater, primarily from dewatering underground workings from natural groundwater ingress to allow to enable continued production (Cohen, 2002). Mines commonly discharge this water into adjacent streams through an environmental pollution licence under the Protection of the Environment Operations (POEO Act NSW (1997). Prior to 1972, there was little regulation for water discharges that contributed to contamination.

A history of poor licencing and lack of targeted legislation surrounding mine planning, developments and knowledge of geochemistry and hydrology of mine sites has led to a legacy of impacts on the watercourses of the region (Lorenzelli et al., 2018; Wright et al., 2018; NSW OEH, 2015; Wright et al., 2017; Cohen, 2002; Belmer et al., 2014; Wright and Burgin, 2009; Lorenzelli et al., 2015; Wright, 2011; Wright et al., 2015; Wright et al., 2011). Key issues include the formation of acid mine drainage (AMD) from adits at Berrima and Canyon Colliery as well as AMD in underground workings due to fractures in coal seams seen at Clarence Colliery (Cohen, 2002; Wright and Burgin, 2009; Wright et al., 2018). Additionally, alkaline treated mine discharge from Clarence Colliery has been remobilised in the naturally acidic receiving waters of Wollangambe River (Lorenzelli et al., 2018). Subsidence also impacts stream flow such as the impacts of Tahmoor coal mine on Redbank Creek (Wright et al., 2015). These legacy issues are of serious concern as most of these mines either drain into National Parks and World Heritage Areas e.g. Clarence colliery, Canyon Colliery or drain into Sydney's drinking water supply e.g. Berrima Colliery. The impacts encompass chemical, biological and physical effects such as impacting stream chemistry, reducing macroinvertebrate abundance and species richness and changing stream flow by either draining watercourses from subsidence or significantly increasing base flow seen at Canyon Colliery by 60% and Clarence Colliery by 90-95% (Wright and Burgin, 2009; Lorenzelli et al., 2018; Belmer et al., 2018; Wright et al., 2017).

A substantial amount of these mines in Sydney are now derelict under the Mining Act (1992), with remediation of these site restricted by budget. There are over 570 derelict mines in NSW alone with a total remediation budget of approximately $3 million per annum (NSW Government Environment and Planning, 2018). Although the Mining Act (1992) ensures remediation of mine sites post closure through bonds, many of these sites closed before 1992 without this regulation. It should also be noted that a history of poor management and mining practices means that remediation is very difficult, if possible at all as subsidence and large-scale AMD is often too difficult to remediate especially in the cases discussed here. Here we discuss the management, licencing and legislation of three mines: two closed mines in Berrima, Canyon Colliery and one operating mine in Clarence Colliery, providing insight into best practice and how these sites can guide future changes in coal mine licencing and legislation.

Study Area

This study reviews 3 of the 9 coal mines that still currently discharge mine wastewater into waterways of the Greater Sydney Region. These mines include Berrima Colliery (1), Canyon Colliery (4) and Clarence Colliery (5) (Figure 1). At these sites, both invertebrate abundance and family richness have been analysed as well as temporal and longitudinal analysis of water and/or sediment chemistry (Lorenzelli et al., 2018; Wright et al., 2018; NSW OEH, 2015; Wright et al., 2017; Cohen, 2002; Belmer et al., 2014; Wright and Burgin, 2009; Lorenzelli et al., 2015).

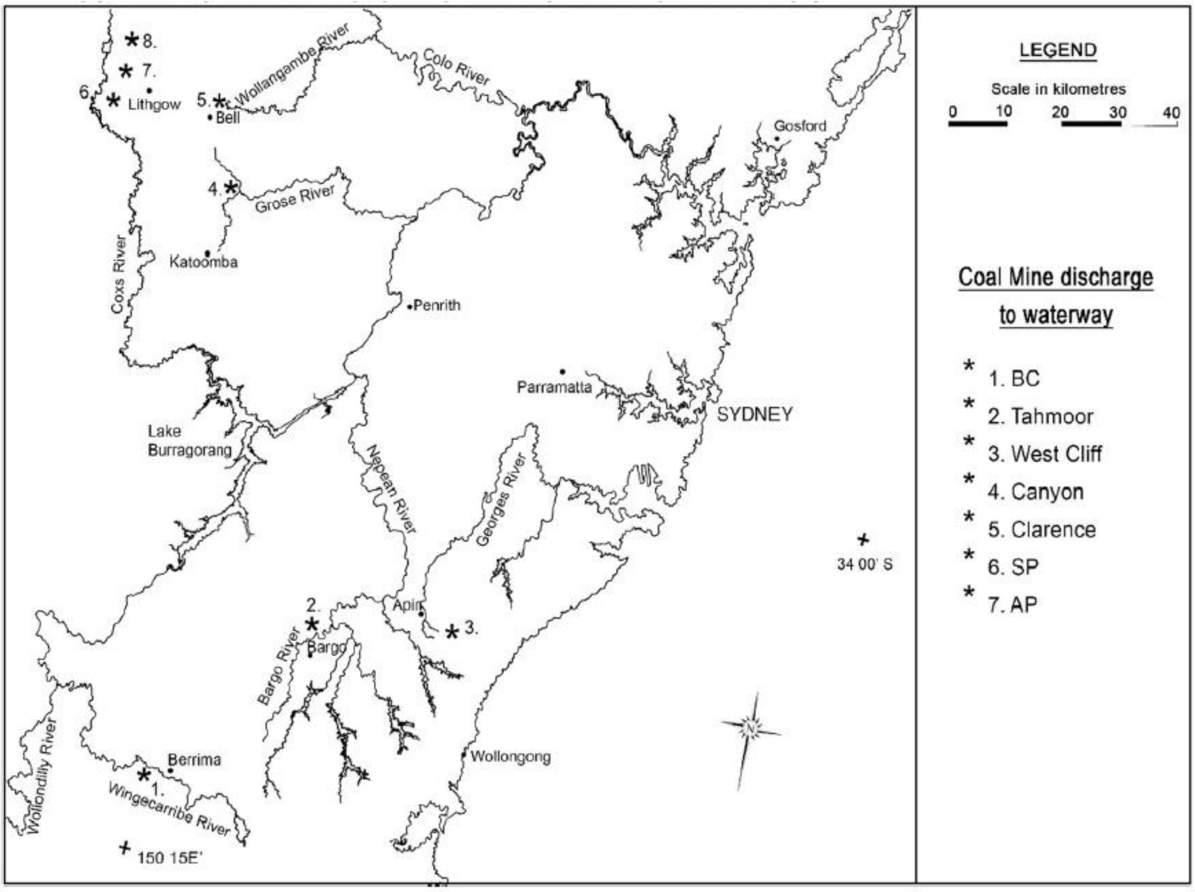


Figure 1: Coal mines currently draining into waterways of the Greater Sydney Region (Taken from Wright et al., 2018).

Berrima Colliery

Berrima Colliery (34°29'8.66"S 150°15'56.09"E) was one of Australia's longest operated mines from 1872-2013 (Figure 1). During production, continuous inflow of groundwater filled underground workings (Wright et al., 2018). This water was pumped and discharged from an adit under EPL608 (Table 1).

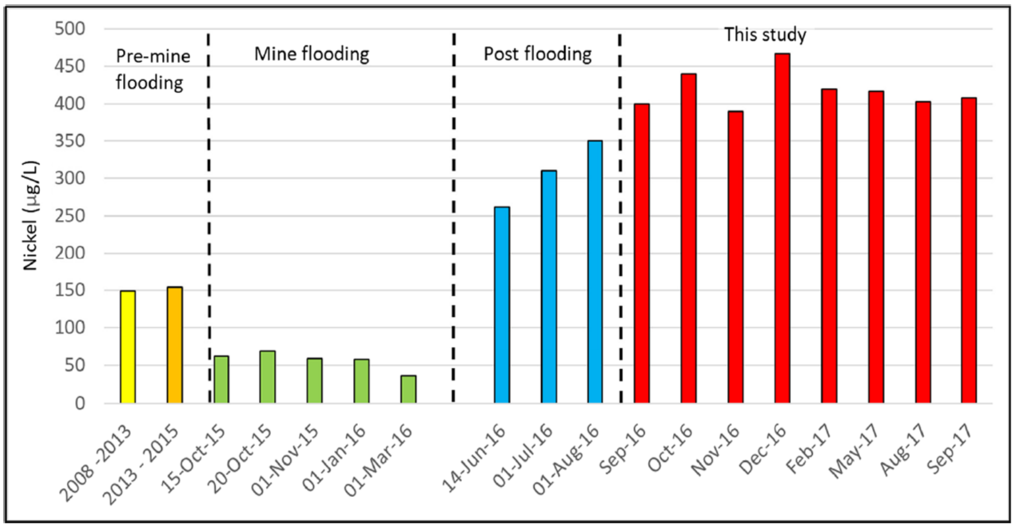
Table 1: Comparison of pollutant discharge concentration limits under Environment Protection Licence (EPL) 558 (Canyon Colliery), 608 (Berrima Colliery) and 726 (Clarence Colliery) compared to ANZECC 2000 Guidelines

Chemical/Parameter	Canyon Colliery EPL 558	Berrima Colliery EPL 608	Clarence Colliery EPL 726 Phase '1' Pre June 5th 2017	EPL 726 'Phase 2' post June 5th 2017	ANZECC 2000 Guidelines
As (µg/L)	No limit	No limit	10	13	13
Bo (µg/L)	No limit	No limit	100	100	370
Cd (µg/L)	No limit	No limit	1	0.2	0.2
Cl (µg/L)	No limit	No limit	25000	25000	No limit
Cr (µg/L)	No limit	No limit	10	1	1
Co (µg/L)	No limit	No limit	No limit	2.5	No limit
Fe Filterable (µg/L)	1000	No limit	300	300	No limit
Fluoride (µg/L)	No limit	No limit	No limit	1000	No limit
Pb (µg/L)	No limit	No limit	5	3.4	3.4
Li (µg/L)	No limit	No limit	No limit	100	No limit
Mn Filterable (µg/L)	No limit	No limit	500	500	1900
Hg (µg/L)	No limit	No limit	1	0.06	0.06

Ni (µg/L)	No limit	No limit	No limit	11	11
Nitrogen (µg/L)	No limit	No limit	No limit	250	250
Oil and grease mg/L)	10	10	10	10	No limit
pH	No limit	6.5-8.5	6-8.5	6-8.5	6.5-8.0
Total Suspended Solids (mg/L)	No limit	50	No limit	No limit	No limit
Oxygen Demand (mg/L)	No limit	20	No limit	No limit	No limit
Phosphorous (µg/L)	No limit	No limit	No limit	20	20
Se (total) (µg/L)	No limit	No limit	10	5	5
Ag (µg/L)	No limit	No limit	1	0.05	0.05
Sulphate mg/L	No limit	No limit	250	250	No limit
Zn (µg/L)	5000	No limit	1500	8	8

The EPL licence permitted discharge of mine wastes which required few analytes namely oil and grease, total suspended solids, pH and biochemical oxygen demand. When the mine ceased production in 2013, there were concerns around the rehabilitation of the site. The Mining Act (1992) stipulates several specific guidelines issued by DRE covering the sealing of mine entries, calculation of rehabilitation bonds and closure planning. As well as the Mining Act, mine closure plans need to be considered under the Environmental Planning and Assessment Act, and for this mine clause 12 of the State Environmental Planning Policy (Sydney Drinking Water Catchment) 2011. These requirements call for mine discharge to have a neutral or beneficial effect assessment to ensure it has no effect on the receiving drinking water catchment.

However, data from Wright et al (2018) indicates the mine is currently negatively impacting the Wingecarribe River It is also likely that due to a lack of analytes in the licence, negative impacts are/were unlikely to be detected in the past. A lack of treatment prior to discharge would have led to considerable contamination as well. The negative impacts post closure stem from groundwater ingress into the old mine workings. Post mine closure, pumping of groundwater ceased (Wright et al., 2018). This resulted in flooding of 15% of the underground workings, resulting in contaminated discharge exiting the adit (Wright et al., 2018). This kind of contamination is consistent with UK based studies and is known as the 'first flush' of contamination (Cairney and Frost, 1975; Younger, 1993; Banks et al., 1997). As groundwater ingress occurs, oxidation of sulphides in the exposed coal leads to the release of soluble metals. This is indicated from the increase in manganese, zinc and nickel (Figure 2). After the first flush, nickel and manganese concentrations have remained above the first flush of contamination (Figure 2) (Wright et al., 2018). This appears to be due to the formation of AMD as pH gradually dropped post-flooding from a mean of 7.5 to 6.25–6.51 (Wright et al., 2018). This is a significant issue as once AMD production continues without management intervention; the pH will continue to drop leading to further increases in metal solubility.



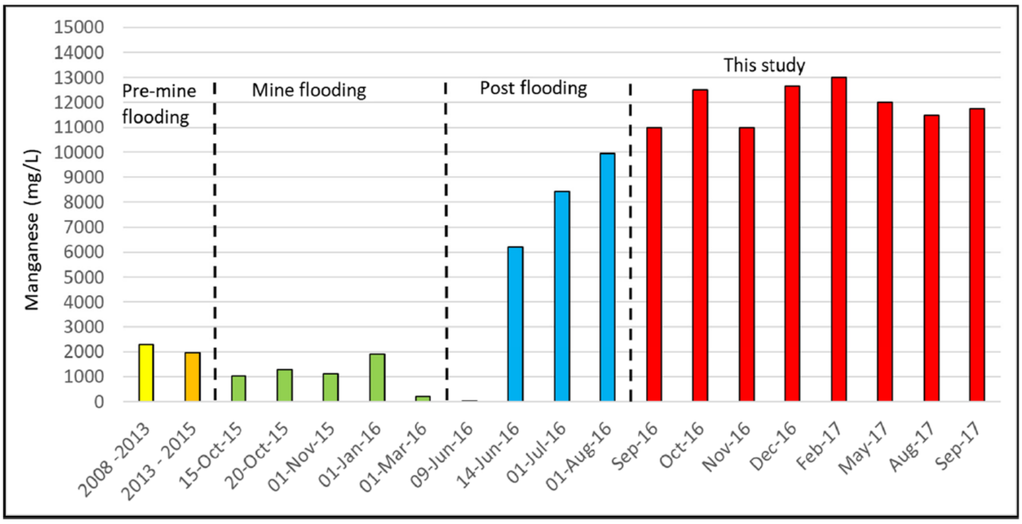


Figure 2: Mean manganese and nickel in Berrima mine drainage, including historic data (2008 to August 2016) and data from the Wright et al., 2018 study. The first two bars represent 'pre-mine flooding', the first (yellow) bar was during mine operation, the second (orange) bar was during 'care and maintenance' with mine drainage pumped. The five green bars 'Mine Flooding' was the period when the lowest mine workings were flooded. The four blue bars were after the flooding when the mine returned to free-draining. The last eight (red) bars were collected during the 13-month period of the Wright et al., 2018 study (Taken from Wright et al., 2018).

The main concern for this site is how to manage it post-flooding. One potential strategy is to seal the mine. However, there is potential that pressure could build up in the mine as groundwater ingress reaches natural equilibrium. This could result in catastrophic outbursts that would flood the Wingecarribe River, in turn contaminating Sydney's drinking water. The placement of the adit also complicates future management as it sits below the natural water table; hence, contamination will continue to occur if the adit is left to drain by AMD exiting the adit into the river.

Canyon Colliery

Canyon Colliery (33°32'3.40"S 150°16'54.75"E) is located near the township of Bell in the Blue Mountains (Figure 1). The underground mine operated from the 1930's-1997. In the late 1970's, two drainage adits were constructed to drain water from the mine (Macqueen, 2007). The water discharged into Dalpura Creek directly from the adits under EPL 558 (Table 1), flowing into the Grose River. The EPL only specified discharge concentrations for oil and grease, iron and very high levels of zinc. This discharge was not treated. From the drying of creeks and upland wetlands above the mine, it appears that subsidence has resulted in fractures in the overlying geology resulting in the increase of water discharged from the adits towards the end of mine's operation and post closure (Macqueen, 2007). This has resulted in the production of significant volumes of AMD, estimated to be 65% of the upper Grose River discharge (Macqueen, 2007; Wright and Burgin, 2009). The clear significance of the mine's impacts is evident due to its location in the upper catchment, lack of other anthropogenically effected drainage sources and its location within the Blue Mountains National Park. The discharge introduces zinc at a mean of 594.7µg/L, nickel at 235µg/L and cobalt at 25µg/L (Wright and Burgin, 2009). The result of the increase in metal concentrations downstream of the mine discharge has led to 65% reductions in macroinvertebrate species richness and 90% abundance in the upper regions of the Grose River (Wright, 2009).

In terms of site management, the security bond of $133,500 was approved in 1990 and refunded when the EPA licence was surrendered in October 2011. Furthermore, the closure plan didn't stipulate any remediation in respect to the discharge, including only demolition of buildings and revegetation the disturbed area at the surface workings of the mine. However, due to the nature of the location of the adits being only accessible by foot and the nature of the drainage, the only foreseeable management option is to allow sulphides in the ore to keep producing AMD until the sulphide source is spent, which may take decades to centuries to achieve.

Clarence Colliery

Clarence Colliery (33°27'49.75"S, 150°14'47.91"E) is located near Lithgow in the Blue Mountains, NSW, Australia (Figure 1). The mine is located in the headwaters of the Wollangambe River. Mining commenced in 1979 and is still operating today. At the site, 14ML of groundwater infiltrates the underground workings (Cohen, 2002). AMD is produced underground through the inflow of groundwater through fractures in the coal seam producing raw mine water containing a 4.2pH, 0.39mg/L of Co, 2.04mg/L Fe, 2.36mg/L Mn, 0.89mg/L Ni and 2.6mg/L Zn (Cohen, 2002). This water is pumped to the surface where it is treated using a conventional lime treatment plant, sedimentation pond and polishing lagoon to meet the discharge requirements of EPL 726 (Table 1). The water is discharged into the Wollangambe River, 200m upstream of the Wollangambe Dam and a further 1.5km from where the river enters the Blue Mountains National Park (Lorenzelli et al., 2018).

Numerous studies have identified the impacts of the mine discharge on the Wollangambe River with widespread impacts noted as early 1996 (Jones and Riley, 1996; Jones and Earnes 1996). These studies identified that the treatment was not adequately treating the AMD with considerable volumes of metals being remobilised in the sedimentation pond and polishing lagoon, which was being discharged into the protected Wollangambe River. The elevated quantity of metals in the sediment and water of the stream was also noted, which was further reinforced by Cohen (2002). It was not until the Belmer et al. (2014) study, further depicting the impact of the discharge particularly on macroinvertebrate assemblages, that prompted an OEH investigation in 2015 that identified that the discharge was a high-volume source of contamination extending up to 22km downstream the River that major changes were made to EPL 726. This can be seen in Table 1 in Phase 1 and Phase 2 of the licence.

The new licence imposed some of the strictest discharge controls for an Australian coal mine. The new licence is based on the ANZECC guidelines (2000) and covers a larger suite of analytes including metals not included in the ANZECC guidelines but present at high concentrations in the discharge such as zinc, nickel and cobalt. However, a recent study on the site by Lorenzelli et al. (2018), highlights the need for licencing to be based on the natural conditions of the receiving water, guided by an understanding of the local geochemistry. The study showed that the mine discharge inputs mainly soluble as well some precipitated metals into the river as well as a significant volume of metals present in the sediment. The soluble metals indicate the treatment is failing to treat the AMD. However, the precipitated metals highlight an issue of remobilisation. Metals were remobilising in the Wollangambe Dam 200m downstream of the discharge where cobalt, zinc and nickel metals were all almost 100% soluble. Leaching tests of sediments downstream of the discharge prior to the dam indicate pH plays a significant role. This is an issue as the mean pH of the discharge is currently 7.45, compared to the natural pH range of 4.9-5.35. This raises a serious legacy issue. The data presented shows that as the pH drops to the natural conditions, concentrations of zinc increased from 0.12mg/L at pH8 to 30.6mg/L at pH5 with nickel and cobalt increasing from 0mg/L and 0.18mg/L to 3.3mg/L and 19mg/L respectively, significantly surpassing background conditions and ANZECC guidelines.

Table 2: pH dependence of metals extracted from discharge sediments with comparison to the concentration of metals in discharge sediment, EPL 726 and ANZECC 2000 Guidelines (Taken from Lorenzelli et al., 2018)

	pH							
Metal	8 (mg/L)	7 (mg/L)	6 (mg/L)	5 (mg/L)	4 (mg/L)	EPL 726 (mg/L)	ANZECC Guidelines (mg/L)	Sediment Concentration (mg/kg)
Al	0.8	0	0	0	0.7	No limit	pH >6.5 0.005	1966.7
Co	0	0.24	0.68	1.24	3.3	0.0025	No Limit	203.3
Ni	0.18	2.14	4.7	9	19	0.011	0.011	370
Zn	0.12	3.32	11.4	30.6	81	0.008	0.008	896.7
Fe	0	0	0	0	0	0.3	No Limit	9366.7
Mn	0.14	0.88	3.2	9	14.4	0.5	1.9	1066.7

This highlights that the change in EPL726 fails to address the key issue at the site in secondary pollution arising from the remobilisation of metals as pH returns to its naturally acidic state. Guidelines are also incomplete e.g. sediment quality guidelines are available for 9 metals in the ANZECC guidelines. It is evident that the treatment at the site is inadequate for the acidic nature of the receiving waters. Moving forward, licencing should include both total and dissolved analysis of the discharge as well as sediments, as sediment provides an indication of contamination over long periods of time. Successive longitudinal monitoring points down the river are needed to assess remobilisation. Clarence provides an example of a potential legacy issue while the mine is currently operating. Fortunately, a significant amount of the legacy can be remediated through the removal of the sediment in the accessible Wollangambe dam where most of the contaminated sediment is located, diverting flow around the dam while it is dredged and extracted.

Discussion/Conclusion

The main reason for the legacy issues discussed have been due to poor legislation and practice surrounding mine conception, planning, production / treatment methods and pollution licensing. Without strict and enforced legislation and licencing, mining companies are more likely to favour practices that are economically focused rather than environmental focused e.g. digging drainage adits to alleviate drainage issues without understanding the possible geochemical implications as in the AMD at Canyon Colliery. A holistic approach is needed beginning with the mine's conception. This should be based on licencing being responsive to individual site-based conditions reflecting local geology and -geomorphology and water chemistry. AMD is an issue for Sydney coal mines, due to their underground workings and the acidic nature of the receiving waters. Site-based analysis, stricter licencing that includes wider geological analyses and guiding legislation that incorporates geochemical composition of the coal seam, groundwater ingress, water extraction, treatment, discharge, geochemical composition of receiving waters in planning approval are necessary. Together, these factors determine what licencing is necessary, what mining practices should be used, treatment of discharge water and post mine-closure practices.

Clarence Colliery provides a good example of a currently operating mine with potential legacy issues in which strict licencing changes have failed to recognise site-based issues. Even with strict licensing based on ANZECC guidelines, discharge can still contaminate the stream. For example, at Clarence the high discharge pH has allowed precipitated metals to accumulate in the sediment of the river, potentially remobilising post mine closure. Licencing needs to incorporate sediment, total and dissolved metals and well as ionic balance and pH of the receiving waters, especially in the naturally acidic streams of the greater Sydney region. This study suggests that licences need to reflect local conditions, and that ANZECC guidelines can be used to determine toxicity levels of some metals, albeit with critical limitations. Licences are only as effective as their enforcement and the EPA needs significantly more resources. However, legislation should incorporate local geological conditions to better guide management decisions.

Mining practices have been improving. With coal mining in decline and most mines in the Greater Sydney Basin due to close in the next 20 years, improvements to licencing must also have a focus on mine closure and current to future legacy issues. The planning, regulation, management and closure of mines must be reflective of the environmental impacts as well as social and economic concerns. What is evident through these case studies is that operational issues, such as subsidence, licencing, such as AMD, continue to impact on the environment and reputation of the industry and government. Mining in the Sydney basin plays a significant role as a cautionary tale for coal mining domestically and globally, particularly in respect to discharging directly into national parks and drinking water catchment. More research is needed to analyse the mines as they close to reduce any further damage to national parks and drinking water supplies.

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