

# The End of Coal: What are the residual impacts for Australian rivers?

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## Key Points

- As coal mines progressively close down and flood with groundwater the residual pollution of ground and surface waters is likely to contaminate for decades.
- Coal mine and power station owners may resist investing in optimal waste treatment technologies as operations become uneconomic.
- Subsidence fracturing to streams from underground mines will damage stream hydrology, habitat and is likely to continue to leach contaminants into surface and ground waters.
- Current 'state-of-the-art' repairs to subsidence-fractured stream channels appears to be unsuccessful and efficacy has not been rigorously tested.
- Poorly managed power station coal ash waste repositories will probably release harmful contaminants into ground and surface waters for decades.
- Coal ash materials can be used as a raw material for manufacture of many beneficial products

## Abstract

This paper is a summary of multiple investigations on some of the major impacts of coal mines and coal-ash on waterways in NSW. We present a summary of three major environmental problems that we believe will continue to contaminate and impair waterways long after the coal mines and power stations have closed. The first case study is the pollution of mine drainage that can be triggered after the mining stops. It follows the Berrima Colliery case study, before and after it closed in 2013. The closure and flooding of underground workings triggered mildly acidic pH and higher concentrations of several metals, compared to when the mine was operating. The second case study examines subsidence from the Tahmoor Colliery, an underground coal mine. The study investigated Redbank Creek that was extensively fractured by longwalls that made multiple passes directly under it. Salinity and the concentration of metals such as zinc and nickel increased by many times to levels exceeding ANZECC water quality guidelines for aquatic ecosystems. The macroinvertebrate composition of the creek that was strongly impaired had abundant mosquitos. The third case study examines metal-enriched water pollution emerging from one of the many coal-ash dumps across NSW. The closed Kerosene Vale coal-ash dam, near Lithgow, received coal-ash wastes from the nearby (now closed) Wallerawang Power Station for several decades. The ash dam was constructed in a tributary of the Coxs River, near Lithgow, part of Sydney's principal drinking water catchment.

## Keywords

Coal mining, effluent, water chemistry, subsidence, rehabilitation, environmental regulation

## Introduction

Coal mining is a major Australian industry and production has increased steeply since 1970 (Mudd 2009). Coal is Australia's second most valuable export. In 2018-19 Australian exports of coal earned \$69.6 billion per year, rising 14% over the previous 5 years (Australian Government, 2020). In addition to its export, it also provides about 80% of NSW electricity generation (HCEC, 2020). The Sydney Basin is a very productive region, many coal mines in the Sydney basin have ceased production and water pollution from closed mines has been reported in nearby waterways (Price and Wright 2016).

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Despite the importance of the coal mining industry, there have been few Australian research studies that investigated water quality changes as an underground coal mine goes through the closure process. The majority of published literature on this topic comes from the northern hemisphere, particularly from the UK, where the majority of their coal mines closed in recent decades (e.g. Johnson 2003). Many studies have revealed that water pollution from closed coal mines has often increased following the mine closure (Johnson 2003). In NSW an inadequate \$A4.1 million in NSW Government funding for the 2014-5 financial year was provided for rehabilitation of derelict mines yet royalty payments of approximately \$A1.5 billion per annum, were received by the NSW Government from the coal mining industry (Geary 2015).

Environmental damage to waterways (streams, rivers and wetlands) can be triggered by subsidence caused by underground longwall coal mining. The subsidence of the surface landscape is due to movement and fracturing of geological strata from the progressive underground removal of the coal seam. This can cause changes to surface and groundwater hydrology (Krogh 2007; Jankowski 2007). In March 2020 the NSW Government approved the extension of the Metropolitan mine directly under the catchment and one of Sydney's drinking water storages, Woronora Reservoir (Cox, 2020).

Coal currently represents 81% of New South Wales (NSW) electricity generation. However, NSW coal-fired electricity generation is expected to end in 2042, when the last of the State's five operating coal-fired power stations (Mount Piper) is set to close (HCEC, 2020). By far the greatest discharge of water pollutants from coal-fired power stations are toxic metals released from the millions of tons of coal ash waste generated annually by power stations and dumped into unprotected landfills and mine voids. Many ash dumps leach trace elements to the surrounding groundwater and surface water when water in the ash is allowed to percolate out of the landfill/dam and into local surface and groundwater (HCEC, 2020).

Three case studies are examined for this paper, representing examples of long-term impacts that could cause long-term impairment of waterways from closed coal mines or closed coal-ash facilities. We suggest that the NSW Government and the coal and coal-fired power industries consider how they will fund and manage the ongoing environmental impacts that Australian waterways are likely to suffer as we approach the closure of these industries.

## **Case studies**

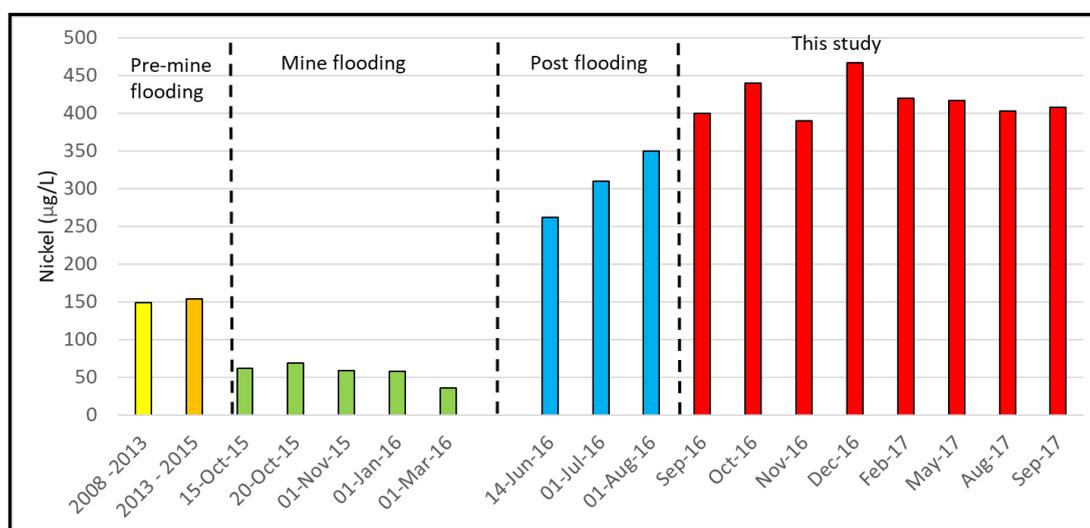
### *Coal mine closures: Berrima Colliery case study*

Water pollution from coal mines can increase after mining ceases, pumping stops and the workings floods with water. The post-mine accumulation of groundwater in the UK has been called 'rebounding' as the rising groundwater level increases until it reaches the surface (Younger, 2002). This phenomenon was first documented at an Australian mine, Berrima Colliery (NSW Southern Highlands). Berrima Colliery was one of Australia's oldest continuously operating coal mines, dating from the 1870s. It ceased operation in November 2013. Groundwater then progressively accumulated in the mine from November 2013 to June 2016. This flooded many of the deeper sections (c.15%) of the underground mine workings. From June 2016 the mine began to free-drain with an average of 2.5 ML of untreated mine drainage emerging from a drainage adit that flowed approximately 80m to the adjacent Wingecarribee River (Wright & Belmer, 2018; Figure 1). A 13-month water quality and ecological study was conducted on this mine, with the mine owner providing unpublished water quality data from when the mine was operating. Methods and detailed results are available (see Wright & Belmer, 2018).

The post-mining accumulation of groundwater within Berrima Colliery triggered a sharp deterioration in mine drainage water quality. Unpublished data from the mine revealed that pH of the Berrima drainage was mildly alkaline when the mine was operating. The drainage pH then fell (after the mine workings were flooded) from 7.74 in June 2016 to 6.25 in February 2017 (Wright & Belmer, 2018). The change in pH was associated with the rising sulfate concentration in the mine drainage that was about 220 mg/L when the mine operated (2008-2013) rising to a peak of 395 mg/L, in September 2016.



**Figure 1. (left) Berrima Colliery mine drainage emerging from drainage adit. (right) Sampling river invertebrates in Wingecarribee River 200 meters downstream of entry of Berrima mine drainage.**



**Figure 2. Mean nickel concentration (µg/L) in Berrima mine drainage, including historic data (2008 to August 2016) and data from Wright & Belmer, 2018 (labelled ‘this study’).**

The concentration of several metals in the mine drainage steeply increased after the mine flooded. Zinc was one of several metals that were of ecological concern. Historic data on zinc levels in Berrima Colliery mine drainage water reported mean zinc concentrations in the mine drainage of 254 µg/L during mining (2008-2013). When the deeper workings in the mine flooded (October 2015 to March 2016) the concentration of zinc ranged from 115 to 212 µg/L. It then increased by more than ten times in July 2016 (2390 µg/L), reaching a peak in Aug 2016 (2410 µg/L). Unpublished data from the coal mine showed that the mean nickel concentration in mine drainage was 149 µg/L when the mine was operating. After the post mine closure flooding, the nickel content initially fell, reaching a low of 36 µg/L in March 2016. Nickel concentrations then increased steeply after the mine flooding (Oct 2015 to March 2016) to 262 µg/L in June 2016. Nickel then progressively increased each month until it recorded a maximum of 466 µg/L, in Dec 2016 (Figure 2).

One of the metals of most ecological concern was zinc. The mean concentration of zinc in the river increased by more than 100 times from a mean of 1.7 µg/L (upstream) to 178.6 µg/L (downstream) during the study. Such a concentration of zinc in the river is ecologically hazardous as ANZECC (2000) recommend a trigger value of 8.0 µg/L for protection of 95% of aquatic species. The mine drainage had a mean zinc content of 1161 µg/L of zinc, during the 13-month study. The ecological impact of the mine drainage inflow on the river was substantial. It caused a 63% reduction in macroinvertebrate family richness (downstream of the drainage inflow) and also an 90% reduction in proportion of invertebrates from the three pollution-sensitive orders (Ephemeroptera, Plecoptera and Trichoptera). Of additional concern was that the mine drainage was

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untreated and was causing pollution of an environmentally sensitive river in the water catchment of Australia's largest domestic water supply dam (Wright & Belmer, 2018).

Results of the Berrima study question the effectiveness of the regulatory regime imposed on this mine through the closure process. The environmental licence (EPL no. 608), enforced by the NSW EPA (NSW EPA 2017a), authorised the release of mine effluent to the Wingecarribee River. During the mine closure the licence only regulated four pollutants (oil and grease, total suspended solids, pH and biochemical oxygen demand) with specified discharge limits. The five most ecologically hazardous pollutants (nickel, zinc, manganese, iron and salinity) had no specific discharge limits, and thus were effectively unregulated (Wright & Belmer, 2018).

### *Subsidence: Redbank Creek (Picton) case study*

Redbank Creek flows on the urban/rural edge of south-western Sydney and had been impacted by channel fracturing caused by subsidence from Tahmoor Colliery longwall coal mining. Subsidence has undermined and fractured the stream channel and this was investigated through two water quality investigations conducted from mid-2012 to October 2017. For methods and detailed results see Wright et al. 2015 and Morrison et al. 2019. The research revealed that subsidence-triggered channel fracturing causing a complex series of changes to the water quality of Redbank Creek (Figure 3). The salinity of Redbank Creek, from a background level of 230  $\mu\text{S}/\text{cm}$  (upstream), before steadily increasing at the sites within the fractured zones (406 - 1806  $\mu\text{S}/\text{cm}$ ). Salinity at levels above 350  $\mu\text{S}/\text{cm}$  would be considered dangerous for aquatic species (ANZECC, 2000). All sampling sites had very low DO levels under low flow condition, always less than recommended guidelines of 85% saturation. The lowest DO mean levels of 2.7% were anoxic and were recorded at RB4, a site where upwelling groundwater entered the stream in an extensively fractured section of the creek (Morrison et al. 2019). Such depleted levels of oxygen would be fatal for most forms of aquatic life (ANZECC, 2000).



**Figure 3. a). Left. Heavily fractured section of Redbank Creek channel; Right. Redbank Creek downstream of 'repaired' section several weeks after rain (2 March 2021)**

The concentration of metals in Redbank Creek was strongly modified in the subsidence fracture zones. The metal that showed the largest increase was iron. It increased from a mean of 3933  $\mu\text{g}/\text{L}$  (upstream of subsidence) to 9700  $\mu\text{g}/\text{L}$  and 52818  $\mu\text{g}/\text{L}$  in the fractured zones. The mean manganese concentration also increased in the fractured zone from 290  $\mu\text{g}/\text{L}$  (upstream) to 4954  $\mu\text{g}/\text{L}$  (in fractured zone). Nickel and zinc concentrations in Redbank Creek were often at concentrations exceeding recommended toxicants for protection of 95% of aquatic species (ANZECC, 2000). The mean nickel concentration was  $<1$   $\mu\text{g}/\text{L}$  upstream of the fracturing. Nickel increased at all sites within the fractured zone (4.5  $\mu\text{g}/\text{L}$  to 41.2  $\mu\text{g}/\text{L}$ ). The mean zinc concentration was 10.4  $\mu\text{g}/\text{L}$  upstream of the fracturing also increasing at all sites within the fractured zone (15.6  $\mu\text{g}/\text{L}$  to 91.5  $\mu\text{g}/\text{L}$ ).

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Macroinvertebrates were also collected from three sites along Redbank Creek in 2014 (Wright et al. 2015). Mosquito larvae and pupae were very rare upstream (RB1: mean 0.64%) but they dominated samples at the two sites in the fractured zone (RB2: mean 67% and RB3: mean 60.4 %). The water quality at these two sites was very poor (very low DO, elevated salinity and elevated metals) and it was apparent that only mosquitos could tolerate the conditions in the fractured zone.

NSW Government regulators have required Tahmoor to repair damage to the damaged creek channel and in mid-2020 a series of 'grout-curtains' were installed. This was attempted by drilling a line of holes in the fractured rock across several damaged sections of creek channel, up to 16 meters deep, and injecting a polyurethane liquid (SIMEC, 2021). After very heavy rain in February 2021 the increased stream flow the creek water continued to flow through highly fractured section of creek (Figure 3). The creek channel of at least one 'repaired' fractured zone remained dry with upstream flow seeping through the fractures. Two weeks later much of the creek flow in the highly fractured section remained dry, but downstream flow emerged, and was coloured an orange-ochre colour (Figure 3). Further investigation is required to establish the efficacy of the remediation methods. In April 2021 the NSW Independent Planning Commission recommended approval to extend the operation of Tahmoor Colliery despite reservations questioning the effectiveness of the remediation measures (recommendation # 112):

*"The Commission acknowledges that the Applicant has identified instances where remediation has led to improved water retention in the subsidence-damaged sections of Redbank Creek and Myrtle Creek; however, data is not available on the long-term efficacy of the Applicant's adopted creek-bed remediation methodology."* (IPC, 2021)

### ***The growing coal-ash problem: Wallerawang (Kerosene Vale) Ash Dam case study***

Coal currently represents 81% of New South Wales (NSW) electricity generation. However, NSW coal-fired electricity generation is expected to end in 2042, when the last of the State's five operating coal-fired power stations (Mount Piper) is set to close (HCEC, 2020).

The greatest discharge of water pollutants from coal-fired power stations are toxic metals released from the millions of tons of coal ash waste generated annually by power station boilers and dumped into unprotected landfills and mine voids. We estimate about 40 percent of all the coal ash generated in Australia is from NSW coal-fired power stations - a disproportionate contribution to the countries' third largest waste stream which represents 20 percent of all Australia's total waste produced, and a consequence of the high ash content of the NSW bituminous coals (HCEC, 2020). While pollution control measures have been employed at all NSW operating ash dumps to varying standards and levels of success, none are lined with an impermeable membrane, which is international best practice. The ash dumps therefore leach trace elements to the surrounding groundwater and surface water when water in the ash and rain is allowed to percolate through.

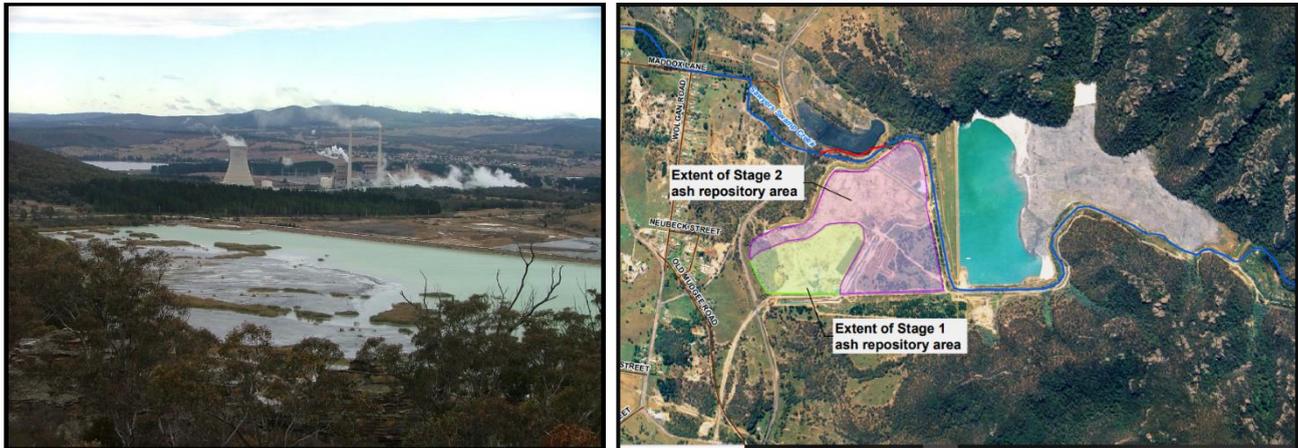
The burnt coal ash was once commonly transported as a slurry and dumped into ash dams. Although, more recently coal ash also dumped in dry ash disposal emplacement, or into disused mine voids. It has been estimated that the total coal ash waste accumulated in NSW is just over 200 million tonnes. Closed power station, such as Wallerawang (Figure 4) have left behind contaminated ash dams and also dry coal ash dumps.

Water quality in Sawyers Swamp was investigated over several years (Belmer & Wright, 2020) and more recently by HCEC (2020). Sawyers Swamp is the creek that was historically used for decades as a dump for coal-ash slurry from the (now closed) Wallerawang Power Station (Figure 4). It was impossible to determine the exact contribution of pollutants from the coal ash as this creek was previously used to dispose of coal mine effluent from the nearby Springvale and Angus Place Collieries (Belmer & Wright, 2020). Recently collected water quality data collected (2018-2020) from Sawyers Swamp, below the ash dam, was compared to water samples collected upstream (2015-2017; Belmer & Wright, 2020). Results showed that the metals (cobalt, nickel, zinc, barium, lithium, and strontium) were all detected at greater concentration downstream of the ash dam, compared to upstream. This reflects previous research that has measured the leaching of metals from Australian coal ash samples (Jankowski et al., 2006; Killingley et al., 2001).

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All NSW power station coal ash waste dumps are contaminated sites that must be rehabilitated in a manner that reduces, and ultimately prevents future leaching of metals into groundwater and surface waters. HCEC believes this could be achieved at least cost by providing assistance to companies wishing to produce safe high volume coal ash waste products (HCEC, 2020). Based on published data, NSW Treasury documents, and HCEC water and sediment testing, we conclude that the NSW Government is liable for considerable decontamination works at the six active power station ash waste dumps when these facilities are decommissioned, as well as for at least one decommissioned ash waste dump (HCEC, 2020).



**Figure 4. Left. Wallerawang Power Station (photo by Ian Wright) and the Kerosene Vale coal-ash dam (Sawyers Swamp) in 2012. Right. Air photo of Kerosene Vale ash dam and the adjacent Stage 1 and Stage 2 dry-ash repository (from Energy Australia).**

## Conclusion

Over more than two decades we have investigated water pollution, disturbance and associated ecological impacts of active and closed coal mines and coal-ash facilities. Despite the importance of coal mining and coal-fired electricity in Australia it appears that water pollution and ecological degradation from mines and ash from power stations will remain an ongoing problem for future decades (Figure 5). Our concerns are supported by the inadequate regulation, rehabilitation and sustainable management of both active and closed coal mines and power operations (Graham and Wright, 2012). Australia regulators seem unaware that water pollution from closed coal mines often increases following the mine closure (Johnson 2003). The outlook for effective repairs to subsidence-fracturing of creek channels is very poor. Of serious concern is that that State Government funding for ongoing management of closed mines in NSW is a relatively paltry \$4.1 million in NSW Government funding for the 2014-5 financial year (for rehabilitation of derelict mines (Geary 2015)). The NSW Government owned and operated the coal-fired power stations before selling them to private interests. The costs associated with rehabilitating the coal-ash dumps will be enormous and liability is almost certain to be contentious.

## Acknowledgments

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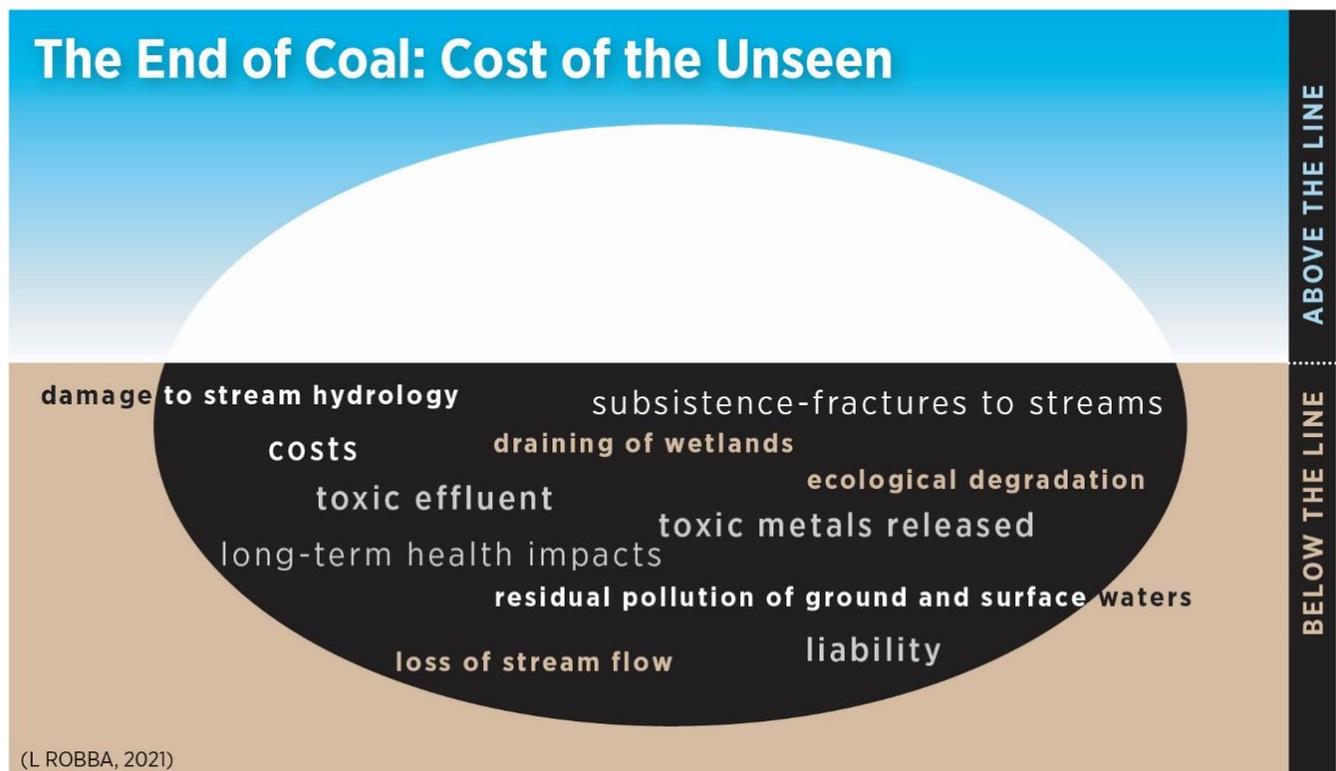


Figure 5. Conceptual model for 'The End of Coal: Cost of the Unseen' representing the many residual impacts that will continue to impair many Australian water resources (Source: Leo Robba).

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