Review of Dendrobium Mine Extension Project

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I have prepared this report in conformance with Part 31 Division 2 and the Expert Witness Code of Conduct in Schedule 7 of the *Uniform Civil Procedure Rules 2005*, and I am willing to be bound by them.

Scope of this advice

I have been asked to produce an expert report in relation to the Dendrobium Extension Project (Project) that addresses the following questions:

(a) In your opinion, is the Project likely to have a significant impact on aquatic ecology? Please provide reasoning for your answer.

(b) In your opinion, are EPL discharges to Allans Creek likely to result in environmental harm in Allans Creek and or/ downstream environment/s? Please provide reasoning for your answer.

(c) Provide any further observations or opinions which you consider to be relevant.

In providing this advice I have reviewed the relevant environmental assessment materials before the Independent Planning Commission (IPC).

Executive Summary

In my opinion, I expect that the Project is likely to have significant impact on aquatic ecology. I have conducted research on the impact of long-wall induced subsidence and stream channel fracturing at Redbank Creek, in the Picton area. I consider this to be a reasonable comparison as Redbank Creek Picton has a similar geology to the Project area. Based on my research on Redbank Creek, I expect that impacts from the Project on stream ecology are likely, and may include degradation of stream habitat, modification to natural flow regimes, and impairment of water quality. In my opinion, the Project will increase the wastewater volume discharged to Allans Creek. I consider that inadequate information on this activity was presented in any of the environmental assessment materials for the Project. Although not part of the Project, other coal mine wastes ('brine') from Bulli Seam coal mines are also discharged into Allans Creek and I am concerned that the cumulative impact of both coal mine waste discharges are not clearly covered in adequate detail in the environmental assessment materials. Allans Creek is a major tributary of Port Kembla estuary and the discharge of wastewater from the Project may contribute to increased pollution of the estuary in future years.

In your opinion, is the Project likely to have a significant impact on aquatic ecology?

The EIS Appendix E 'Aquatic Ecology Assessment' (AEA) Executive Summary (page iii) makes the following statement:

> The primary potential impact to aquatic ecology associated with the Project is the potential for mining-related subsidence and fracturing of bedrock in overlying watercourses. This has potential to result in diversion of flows, reduction in pool water levels and impact aquatic habitat, flora and fauna in the various watercourses traversing these areas.

I partially agree with this statement. Fracturing of bedrock does alter flows and diminish habitat quality for biota. But my own research on long-wall subsidence (Wright et al. 2015; Morrison et al., 2018; Morrison et al., 2019) has revealed that subsidence-triggered fracturing of stream channels can also cause changes in water quality and inflict substantial adverse impacts to stream ecosystems. This research has been conducted in the southern coalfield of the Sydney Basin in comparable sandstone geology to that of Project. My opinion is that the Aquatic Ecology Assessment produced for the Project understates the potential for adverse impacts, triggered by subsidence, that can cause long-term impairment to stream and river ecosystems.

The Aquatic Ecology Assessment (page 48 of AEA) also makes the following statement, which has important implications for impacts on aquatic ecosystems of surface waters:

> Potential water quality impacts as a result of mining-induced subsidence from the proposed longwalls would be localised (HEC 2019). Although mine subsidence effects can result in isolated, episodic pulses in iron, manganese, aluminium and electrical conductivity, there have been no reports of any measurable effect on water quality in downstream reservoirs in the Southern Coalfield. Potential localised changes in water quality as a result of the Project are expected to result in negligible or undetectable downstream impacts including at Lake Avon and Lake Cordeaux (HydroSimulations 2019).

This statement is factually incorrect. WaterNSW have made statements confirming that metal concentrations in two storages in two 'undermined' catchments have been increasing over several decades (Lake Cordeaux and Lake Cataract). This graph is included in the WaterNSW submission the Independent Expert Panel on Mining in the Catchment (page 24, WaterNSW, 2018).

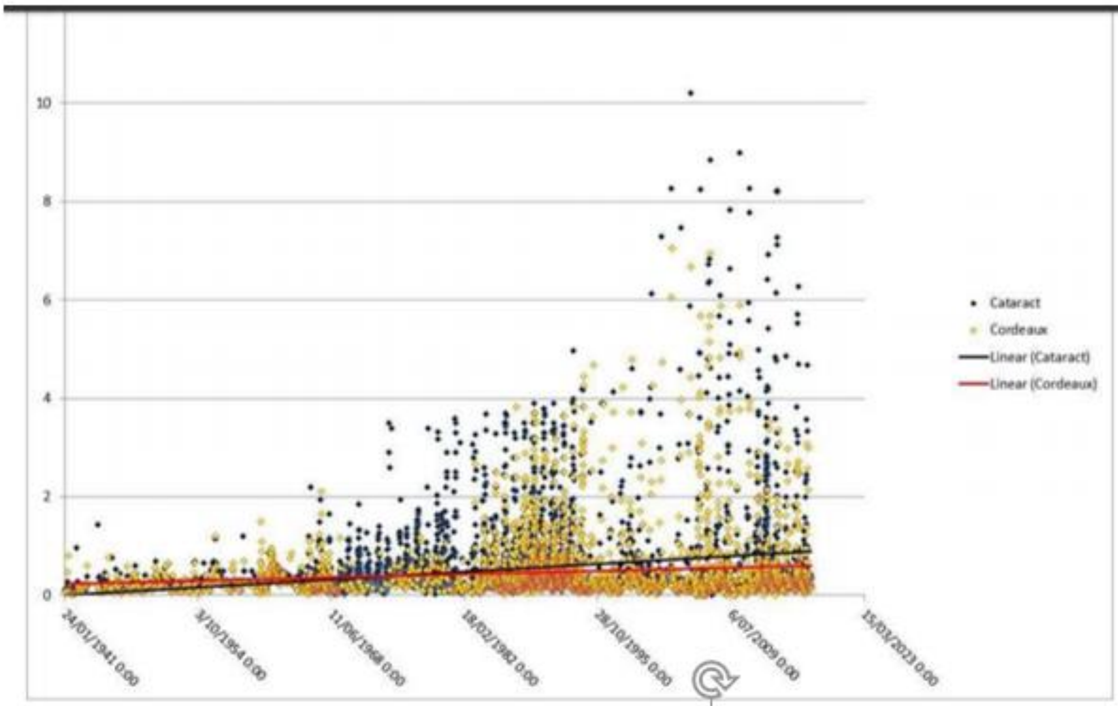


Figure 4-1. Measured iron concentrations in Cataract and Cordeaux Reservoirs

An issue which particularly concerns WaterNSW is that it is anticipated that any additional increases in iron, manganese and possibly aluminum and other species dissolved from undermined catchments will impact on raw water quality delivered to Sydney Water and other customers. WaterNSW applies artificial destratification in most of these storages to manage water quality during summer months. The deep water columns of most reservoirs

Long-wall coal mining can cause substantial and complex changes to stream water quality. This is contrary to the statement from the environmental assessment on the previous page that water quality impacts are likely to the 'isolated, episodic and localised'. I base my opinion on several years of experience and associated peer-reviewed research that I have conducted on water pollution triggered by subsidence and channel fracturing from Tahmoor Colliery on Redbank Creek from 2012 to 2017 (Wright et al. 2015; Morrison et al., 2018; Morrison et al., 2019). This is some of the only peer-reviewed water pollution research done on this topic in Australia. Although based in a different location, it is within the Sydney basin and is likely to be representative of the potential environmental damage to streams and river from the Project. I have made this assumption based on both locations having a very similar geology. It is important to recognise that such independent research is currently very difficult within the Sydney Water Catchment Special Areas which have highly restricted access.

I consider it to be inadequate that this assessment has not reported details and data on potential ecological impacts to the aquatic ecology associated with previous similar underground coal mines in the southern Sydney basin coal fields. The Tahmoor Colliery and Redbank Creek subsidence is only about 10 to 20 km from the Project. It is my opinion that the proposed long-wall mining activity does risk causing substantial habitat and water quality degradation that is likely to cause much greater harm to aquatic ecosystems than is predicted in the assessment documents.

Subsidence - physical, chemical and biological damage to Redbank Creek

I provide the following information as an example of the type of impacts that can be expected to occur as a consequence of the Project.

The subsidence-induced fracturing of Redbank Creek, Picton NSW ranges from small hair-line fractures, to sections of creek channel that can be described as extensive and high-impact. See Picture 1, the section of creek within this subsidence only flowed after heavy rain, with smaller flows disappearing underground through the fractures.

Picture 1: Severe longwall induced subsidence fracturing of Redbank Creek, near Picton. This was upstream of the isolated pool (Picture 1).

Picture 1 shows a section of extreme subsidence fracturing. Whole slabs of sandstone have fractured and been lifted. The Project assessment predicts some occurrence of subsidence and damage to stream channels – damage similar to that observed in Redbank Creek (Picture 1) may potentially result. However, it may be hidden from public view as unauthorised public access to the water catchment is prohibited. I believe that the fracturing damage to the channel of Redbank Creek, due to long-wall subsidence has also been observed within Sydney's drinking water catchments. Images in Dr Peter Turner's Open Letter to the NSW Premier (18 May 2020) [https://ssec.org.au/wp-content/uploads/2020/06/Open_letter_to_Premier_re_mining_in_the_Special_Areas.pdf] has similar images taken from inspections of waterways within Sydney drinking water catchment special areas.

Downstream of the Redbank Creek ‘severe’ fracture zone (Picture 1) were a series of isolated pools in low lying sections of the former creek channel (Picture 2). I have observed pools similar to this over about 1 km of the Redbank Creek channel over the period 2012-2019. These pools all had very poor water quality: very high salinity, elevated metals and commonly with very low dissolved oxygen levels. Whilst the Project assessment suggests that there may be some water quality impacts, the assessment suggests that the impact would be minor and local. I disagree that the likely impacts from subsidence would be local and minor. I base this comment on my observations and research on Redbank Creek from 2012 to 2019, where subsidence has caused impacts that I consider to be of regional impact and substantial in the severity of subsequent pollution. Given that such impacts from the proposed mining activity associated with the Project could occur in a protected water catchment, I consider that any change to surface water quality to be unacceptable. The water quality impacts that I consider to be likely could cause a series of adverse ecological impacts, similar to those that my research documented in Redbank Creek (Wright et al., 2015). This is explained further below.

Picture 2: An isolated pool on Redbank Creek, near Picton. This pool was stagnant, with minimal flow due to extensive channel fracturing and loss of flow from upstream. The mixture of stream water with sections of fracturing rock mobilised minerals and metals and combined to create water quality that was hostile to stream biodiversity.

Picture 3: Severe subsidence fracturing of Redbank Creek, near Picton. This was the site of a ground water 'vent' where upwelling groundwater flowed into Redbank Creek, through a fresh subsidence fracture. Water quality very extremely poor for the aquatic ecosystem with very low dissolved oxygen, very high salinity, and hazardous concentrations of metals such as zinc and nickel (Morrison et al. 2018; Morrison et al. 2019).

The pool in Picture 3 was an upwelling of ground water triggered by subsidence fracturing. The upwelling water had very low dissolved oxygen, almost certainly inadequate for the survival of any stream-dwelling animals. It also had highly elevated salinity and elevated zinc and nickel that together combined to created highly polluted water (Morrison et al. 2018; Morrison et al. 2019).

I consider it to be likely that such subsidence-triggered impacts and damage to stream channels, impairment to stream water quality and degradation to aquatic ecosystems, similar to Redbank Creek, could occur in the future to water catchment waterways due to the proposed Project.

Subsidence fracturing damage to Redbank Creek provided habitat and condition for mosquitos

Picture 4: This pool in Redbank Creek was affected by subsidence and recorded a very high abundance of mosquito larvae and pupae. It also had very few ‘normal’ stream invertebrates.

See Picture 4. I sampled an isolated pool in Redbank Creek that was in a section of creek adversely affected by subsidence, channel fracturing and modification of flow. I sampled this for more than two years and it provided a rich habitat for mosquitos. More sensitive stream invertebrates were missing due to the highly impaired water quality. This pool had depleted dissolved oxygen, very high salinity and elevated zinc and nickel (Wright et al. 2015). This physical subsidence damage to the creek channel, the impaired water quality and adverse impacts to the aquatic ecosystem have all occurred over many years in Redbank Creek. The transformation of a healthy stream ecosystem into dominated by mosquitos is unusual and is a potential ecological impact. It also has potential human health implications, if the mosquito species are disease vectors.

I am uncertain how quickly and effectively repairs/rehabilitation of such damage to stream channels can be achieved. The damage to Redbank Creek was covered by ABC in September 2018 and Sydney Morning Herald in June 2020 (Hannam, 2020). I am yet to observe major subsidence damage to a creek or river channel effectively repaired. I have personally observed repairs to minor channel fracturing in the Georges River, but I am yet to see any evidence that repairs are able to fully repair the damage.

In my opinion the Project assessment fails to provide adequate information on exactly how minor, moderate and severe damage to stream and river channels is to be repaired. Given the repairs ordered for damage to Redbank Creek from Tahmoor Colliery, this location would make an ideal site to demonstrate the efficacy of rehabilitation of a creek channel in sandstone geology that has been shattered by long-wall subsidence (ABC, 2018; Hannam, 2020). I also refer to Dr Peter Turner's Open Letter to the NSW Premier (Turner et al. 2019), of which I am one of several signatories and that I have attached to this report, questioning the proven effectiveness of repairs to stream channel fracturing.

Are EPL discharges to Allans Creek likely to result in environmental harm in Allans Creek and or/ downstream environment/s?

I am aware that current waste discharges from Dendrobium Colliery, combined with wastes from South 32's Bulli Seam Operations ('brine'), are released into Allans Creek via Licenced Discharge Point (LDP) number 5 and are very likely to be causing substantial water quality impairment to the receiving waterways. This is an important issue which is not covered adequately in the Project assessment and further information is required. In my opinion the various assessment documents provided inadequate information on this issue to allow a complete assessment of this issue. I have not seen any detailed data in this assessment that supports the statement from the EIS below, particularly implying that the waste discharge to Allans Creek does not result in any impacts on Allans Creek. Data gaps are a common problem in EISs, but this waste discharge is already an existing activity that I would have expected to be fully investigated and documented. This is a very serious issue and I consider the lack of supporting detail on the water quality and ecological impacts of waste to be a major deficiency.

> In summary, HEC (2019) concluded that the increase in discharge to LDP5 is unlikely to result in an exceedance of the EPL water quality limits or impacts on Allans Creek or any significant impacts to the stability of the channel. A short distance downstream, Allans Creek joins the tidal/estuarine environments of American Creek and the wider Port Kembla area, which is surrounded by various industrial complexes.

The Project assessment does acknowledge that the release of Dendrobium Colliery mine wastewater to Allans Creek is projected to increase (from 6.5 – 9.2 ML/day currently, to 27.6 ML/day in December 2035 (see Figure 17 and Table 27 from the Project EIS below).

What the EIS fails to mention is the current and future projected volume and pollutant composition of 'brine' that is also discharged via LDP 5 from the South 32 Bulli Seam Operations. Although the disposal of 'brine' is not directly related to the Project, it does need to be understood as together both waste sources have a cumulative impact on Allans Creek and other downstream aquatic environments.

How does the pollutant composition, volume and load of the Dendrobium Colliery waste water discharge to Allans Creek compare to the Bulli Seam brine contribution? The environmental impact of the two sources of South 32 mine waste that are released into Allans Creek are potentially very substantial. But only scant information on the Project mine component is outlined in the assessment.

In my opinion it is important to understand how the two sources of South 32 mine waste interact and collectively what is their impact on the downstream waterways and ecosystems. This could be quantified by providing information on the volumes, composition and concentrations and the resulting 'loads' of pollutants discharged, see table 27 below, why is cobalt, salinity (electrical conductivity) barium, strontium, sulfate (and many other typical coal waste pollutants) not mentioned?

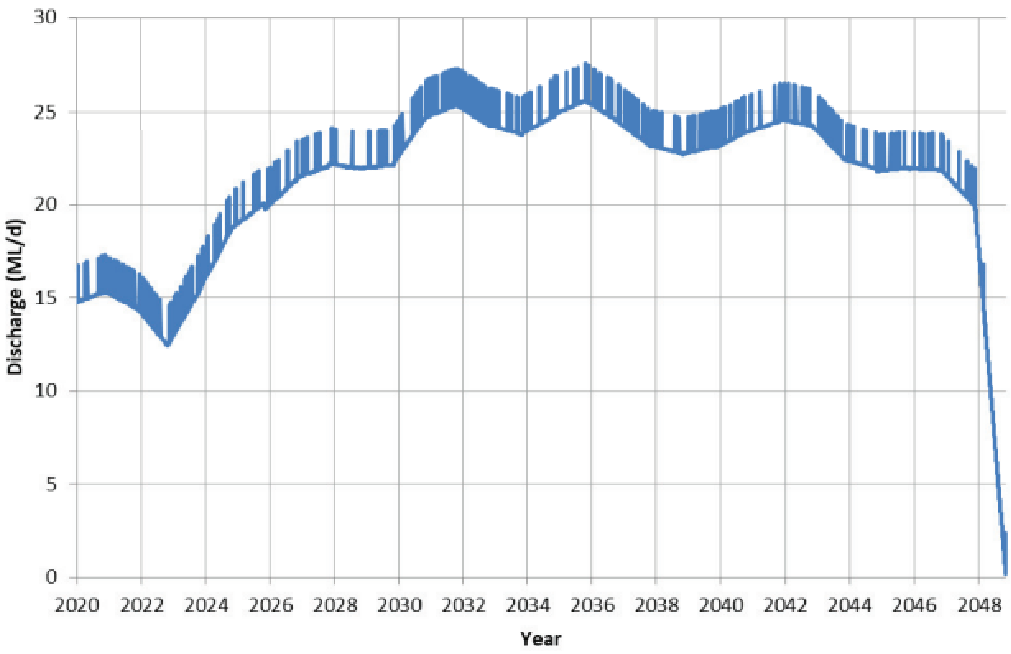


Figure 17 Predicted Daily Discharge to LDP5 for Median Climatic Sequence

Figure 17 shows that the daily discharge rate to LDP5, based on median climatic conditions, is predicted to peak at 27.6 ML/d in December 2035. This compares with an average 6.5 ML/d with a peak of 9.2 ML/d discharge rate obtained from South32 records for the period from May 2014 to September 2018.

Table 27 LDP5 Water Quality and Predicted Area 5 and Area 6 Groundwater Quality

Parameter**	Licence Limit	Monitored Water Quality at LDP5			Predicted Groundwater quality*		
		Min	Average	Max	Min	Average	Max
Arsenic (mg/L)	1.3	0.013	0.015	0.018	0.007	0.008	0.018
Copper (mg/L)	0.08	<0.001	0.001	0.003	<0.001	0.002	0.007
Nickel (mg/L)	5	0.007	0.009	0.015	<0.001	0.016	0.235
Oil and Grease (mg/L)	10	<5	5	7	-	-	-
Total Suspended Solids (mg/L)	30	<5	6	10	-	-	-
pH	6.5 – 9.0	7.7	8.0	8.5	6.8	7.4	8.6
Zinc (mg/L)	0.4	0.017	0.025	0.042	0.004	0.02	0.103

* Source: HydroSimulations (Appendix B of the EIS)

** Licence limits and concentrations of metals are assumed to represent total, as opposed to dissolved, concentrations, however, EPL 3241 does not explicitly state total metals.

Table 27 illustrates that the monitored water quality at LDP5 has been within the licence limits for all parameters. The groundwater quality estimates for Area 5 and Area 6 are within the range of existing concentrations measured at LDP5 for arsenic, copper, nickel, zinc and pH. Therefore, it is unlikely that the proposed increase in discharge to LDP5 will result in a noticeable difference in water quality.

The increase in flow rate discharged to LDP5 has the potential to cause instability in the bed and banks of Allans Creek. However, the bed and banks of Allans Creek are concrete lined in the vicinity of LDP5 and a short distance downstream the creek joins the much larger American Creek and downstream experiences a tidal/estuarine environment. Therefore, the impacts of the additional flow on the stability of Allans Creek are likely to be negligible.

> ### 3.4 SUMMARY
>
> The following provides a summary of the existing and proposed surface facility water management for the Dendrobium Mine:
>
> - Existing water management infrastructure at the Dendrobium Mine operates satisfactorily and in accordance with EPL conditions.
> - The existing water management systems and infrastructure would continue to operate for the Project at the Dendrobium Pit Top, KVCLF, Dendrobium CPP, Cordeaux Pit Top and West Cliff Stage 3 Coal Wash Emplacement for the Project. In addition, no material change in existing water demand or supply reliability is expected to be required for the Project, when compared to the current operations.
> - The key changes to water management for the Project are associated with the new Area 5 and 6 ventilation shafts and increased groundwater inflow predictions.
> - Water management infrastructure (i.e. sediment dams) for the disturbance areas associated with the Area 5 and 6 ventilation shafts would be designed and operated in accordance with Landcom (2004) and DECC (2008) to manage pollution to the receiving environment.
> - Increased groundwater inflows would continue to be managed in accordance with current EPL conditions (i.e. discharge via LDP5), however, additional infrastructure would be required to accommodate the expected increased controlled release volumes. It is understood that South32 is also investigating options for the beneficial reuse of this excess water.
> - The increase in discharge to LDP5 is unlikely to result in an exceedance of the EPL water quality limits or impacts on Allans Creek.
> - Sufficient water supply is predicted in all Project years.

I strongly disagree with the statement in the Project EIS (above: 3.4 Summary) that 'the increase in discharge to LDP 5 is unlikely to result in an exceedance of the Environment Protection Licence (EPL) water quality limits or impacts on Allans Creek'. Comprehensive data needs to be presented to support such a statement, and this also needs to include the contribution of the South 32 mines that also discharge 'brine' wastes under the Dendrobium EPL 3241.

The EPL for Dendrobium Colliery 3241 authorises the discharge of wastewater, without any volumetric limit, and with pollutant concentration that are much higher than ANZECC (2000)[1] trigger values for protection of aquatic species (marine and freshwater). It is my opinion that EPL 3241 provides inadequate protection for Allans Creek and downstream aquatic ecosystems. I will explain my reasoning below:

In August 2020 I was sent a series of water samples that were collected by a citizen scientist from Brandy & Water Creek from upstream of the Dendrobium Colliery surface works, and from a progressive series of sampling sites downstream that had been disturbed by a coal-fine spill that had occurred earlier in August (ABC, 17 August 2020). This included three water samples of 'brine' that was discharged into Allans Creek at LDP 5 by three tanker-trucks (see picture 5 and 6). I assume that the source of that 'brine' was from the South 32 Bulli Seam Operations (Appin area). I base this assumption on EPL 3241, page 9, which states

[1] ANZECC (Australian and New Zealand Environment and Conservation Council) and ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand). (2000). Australian and New Zealand guidelines for fresh and marine waters. National Water Quality Management Strategy Paper No. 4. Australian and New Zealand Environment and Conservation Council/ Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

that the LDP 5: *'Stormwater and minewater discharge from Dendrobium Colliery. Brine discharge from Appin West mine'*.

Discharge quality monitoring

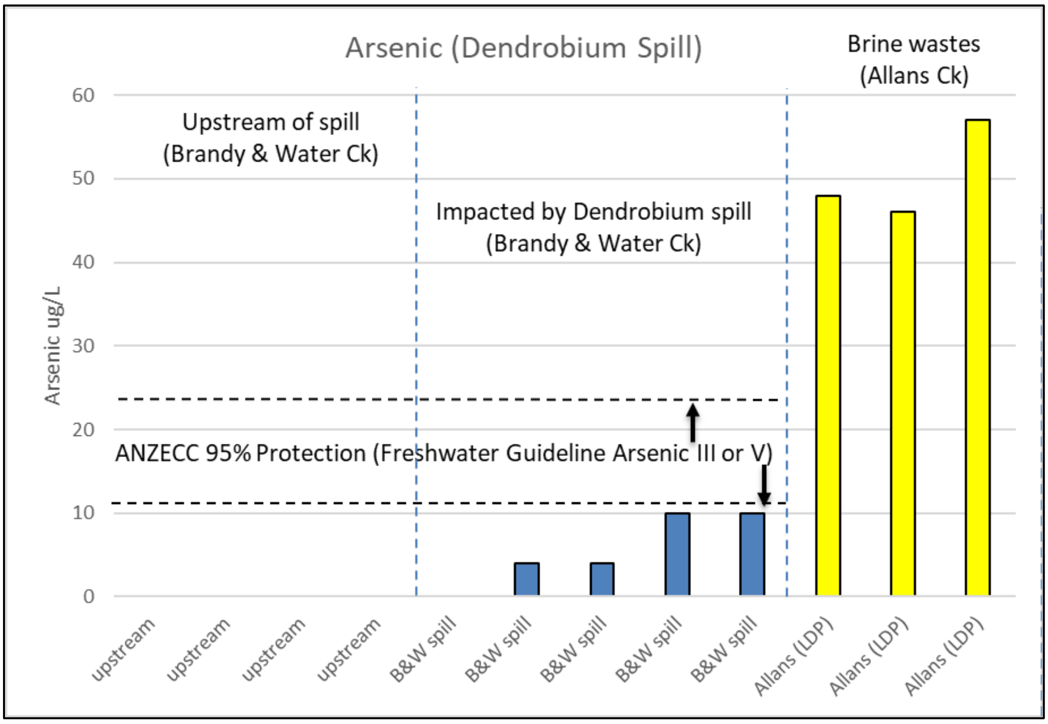
The water samples were sent to me, and I dispatched them to 'Envirolab', a commercial NATA endorsed laboratory for analytical testing of environmental samples. I was confident that the sample were collected using appropriate procedures. The sampling containers were plastic drinking water bottles that were rinsed several times at each sampling location.

I present the key results for three 'brine' samples and other samples, for key metals of concern, in pictures (of graphs) 6 to 10. Based on these results I am concerned that the combined impact of waste discharged via LDP 5 into Allans Creek is causing substantial water quality impacts, which are not explained in the Project assessment. I also make the observation that if wastes are being discharged to the environment using the EPL 3241 for Dendrobium Colliery, then more information should be provided in the Project assessment on the pollutant composition of the brine wastes.

Picture 5: The infrastructure for LDP 5 (EPL 3241) that enables tanker-trucks to discharge their liquid wastes to Allans Creek.

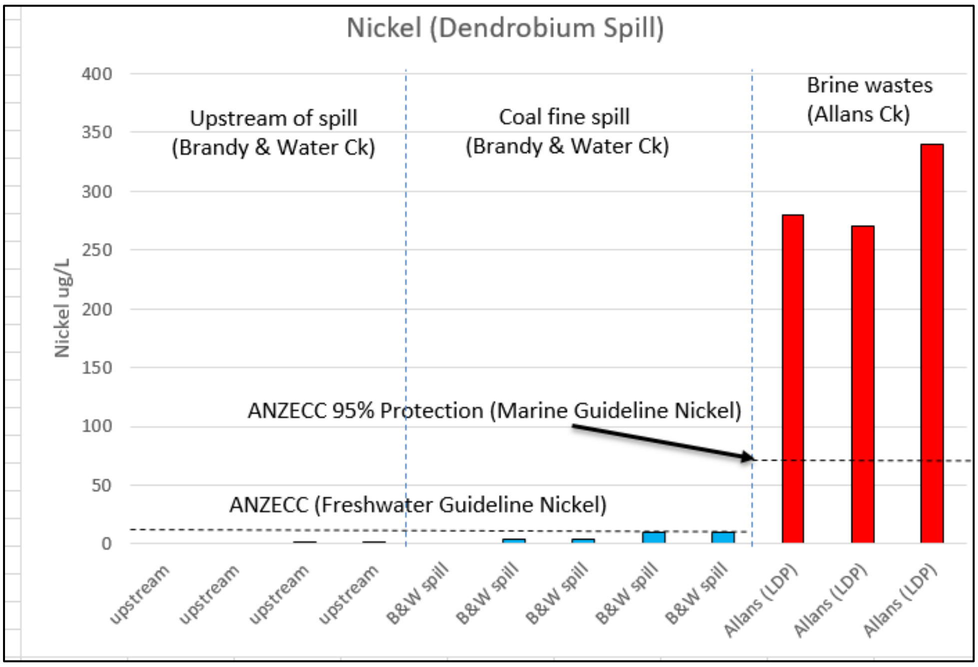
Picture 5 shows the point where tanker-trucks discharge their liquid waste into Allans Creek. Picture 6 shows the release of 'brine' into Allans Creek, in operation in August 2020. Three samples were taken from three consecutive truck-loads of 'brine' waste. The pictures (Picture 8 – 11) graphically display the results for four metals of particular concern, compared to ANZECC (2000) aquatic species guidelines and other water samples collected from waterways further upstream.

Picture 6: The release of wastes through LDP 5 (EPL 3241) from a tanker-truck of 'brine' to Allans Creek.



Picture 7: A graph of Total Arsenic concentrations collected from several sites upstream of Dendrobium Colliery surface workings and several from Brandy & Water Creek (B&W spill) in the vicinity of an August 2020 coal fine spill. Three samples were collected of ‘brine’ as it was releases into Allans Creek via LDP 5 (EPL 3241).

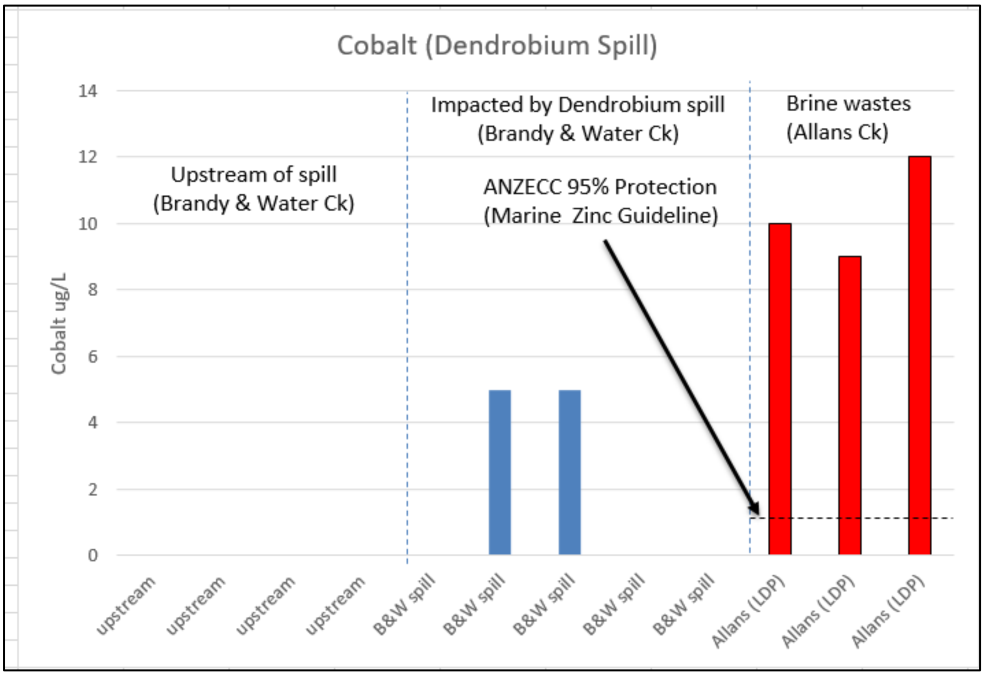
The total arsenic concentrations in the brine were two the three times higher than the total arsenic concentrations quoted for Dendrobium Colliery wastes discharged via LDP 5 (Table 27 on page 5).



Picture 8: A graph of Total Nickel concentrations collected from sites upstream of Dendrobium Colliery surface workings and several from Brandy & Water Creek (B&W spill) in the vicinity of an August 2020 coal

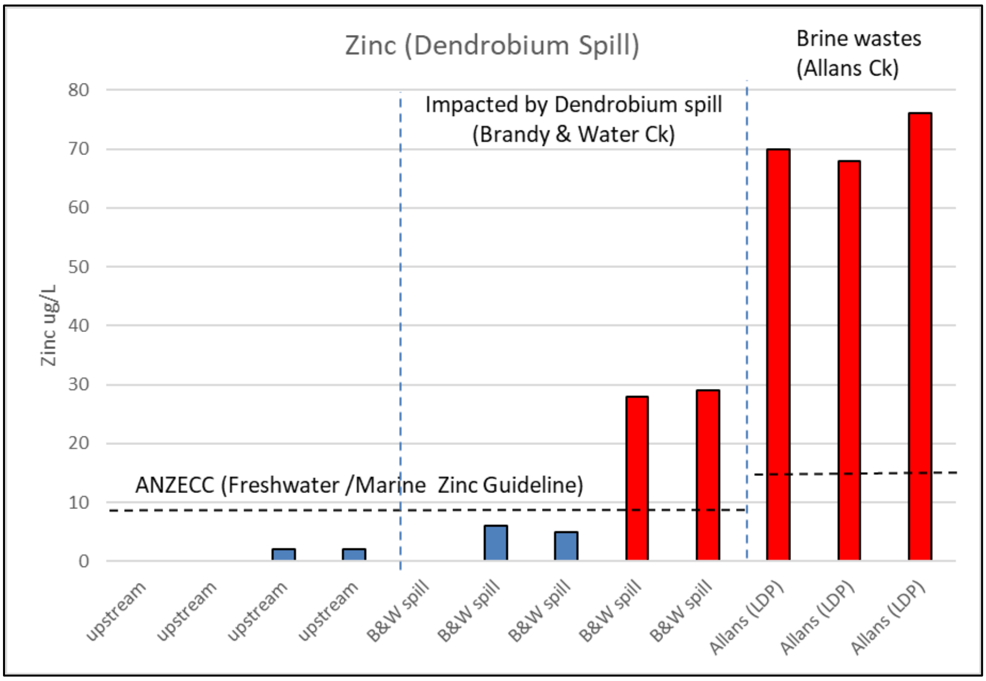
fine spill. Three samples were collected of 'brine' as it was releases into Allans Creek via LDP 5 (EPL 3241).

The total nickel concentrations in the brine were ten to 20 times higher than the total nickel concentrations quoted for Dendrobium Colliery wastes discharged via LDP 5 (Table 27 on page 5).



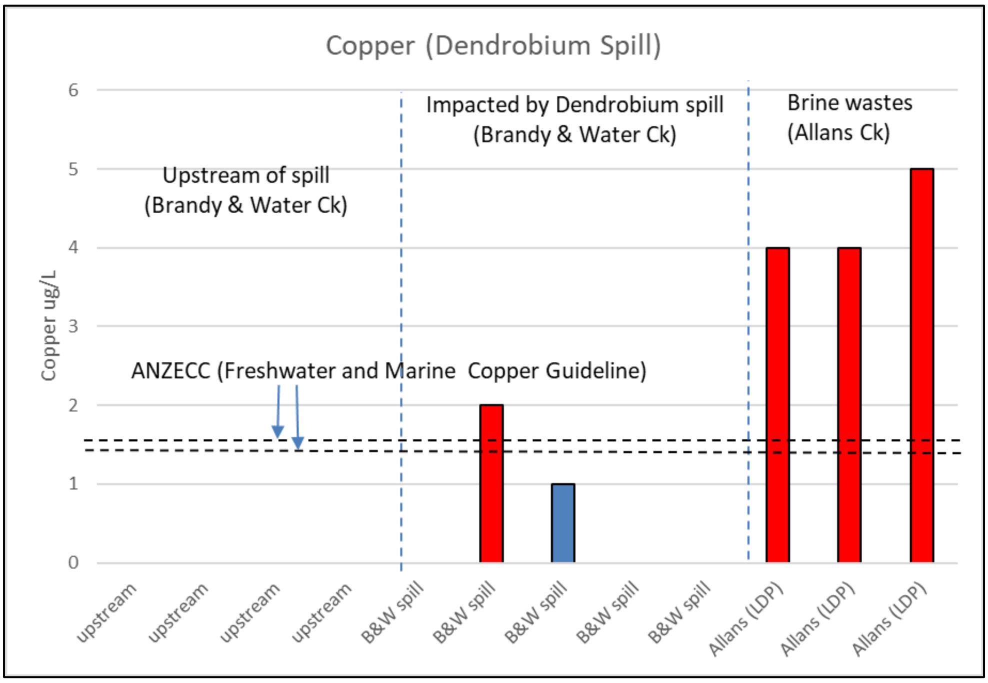
Picture 9: A graph of Total Cobalt concentrations collected from several sites upstream of Dendrobium Colliery surface workings and several from Brandy & Water Creek (B&W spill) in the vicinity of an August 2020 coal fine spill. Three samples were collected of 'brine' as it was releases into Allans Creek via LDP 5 (EPL 3241).

No cobalt concentrations were provided for Dendrobium Colliery wastes discharged via LDP 5 (Table 27 on page 5).



Picture 10: A graph of Total Zinc concentrations collected from several sites upstream of Dendrobium Colliery surface workings and several from Brandy & Water Creek (B&W spill) in the vicinity of an August 2020 coal fine spill. Three samples were collected of 'brine' as it was releases into Allans Creek via LDP 5 (EPL 3241).

The total zinc concentrations in the brine were about 50% higher than the total zinc concentrations quoted for Dendrobium Colliery wastes discharged via LDP 5 (Table 27 on page 5).



Picture 11: A graph of Total Copper concentrations collected from several sites upstream of Dendrobium Colliery surface workings and several from Brandy & Water Creek (B&W spill) in the vicinity of an August 2020 coal fine spill. Three samples were collected of 'brine' as it was released by three trucks into Allans Creek via LDP 5 (EPL 3241).

The total copper concentrations in the brine were about 50 to 75% higher than the total copper concentrations quoted for Dendrobium Colliery wastes discharged via LDP 5 (Table 27 on page 5).

The EPL 3241 100% concentration limits are copied below (Picture 12). They allow very high concentrations of arsenic, copper, nickel and zinc. For all pollutants, the concentrations are much higher than ANZECC (2000) Guidelines. In my opinion such highly elevated concentration limits are hazardous for downstream aquatic species. Given that such highly elevated concentrations of these pollutants have been found in the 'brine' samples, I suggest that a thorough and detailed investigation needs to be conducted to determine suitable discharge conditions that would protect water quality and aquatic species in Allans Creek and in Port Kembla estuary. The investigation needs to consider both sources of South 32 mine waste, Dendrobium Colliery and tthe Project and also Bulli Seam 'brine' that is disposed at the same point. Both source of pollution need to be evaluated individually, and together to assess the cumulative impact on Allans Creek.

POINT 5

Pollutant	Units of Measure	50 percentile concentration limit	90 percentile concentration limit	3DGM concentration limit	100 percentile concentration limit
Arsenic	milligrams per litre				1.3
Copper	milligrams per litre				0.080
Nickel	milligrams per litre				5
Oil and Grease	milligrams per litre				10
pH	pH				6.5-9.0
Total suspended solids	milligrams per litre				30
Zinc	milligrams per litre				0.4

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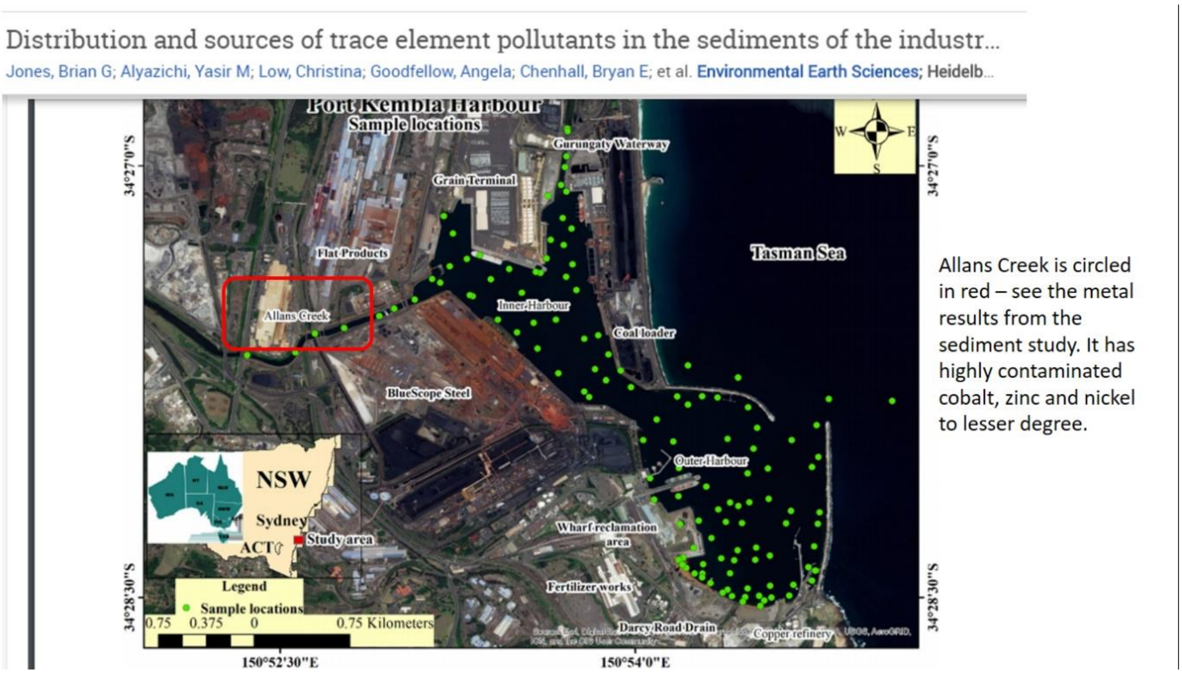
Licence version date: 10-Aug-2020

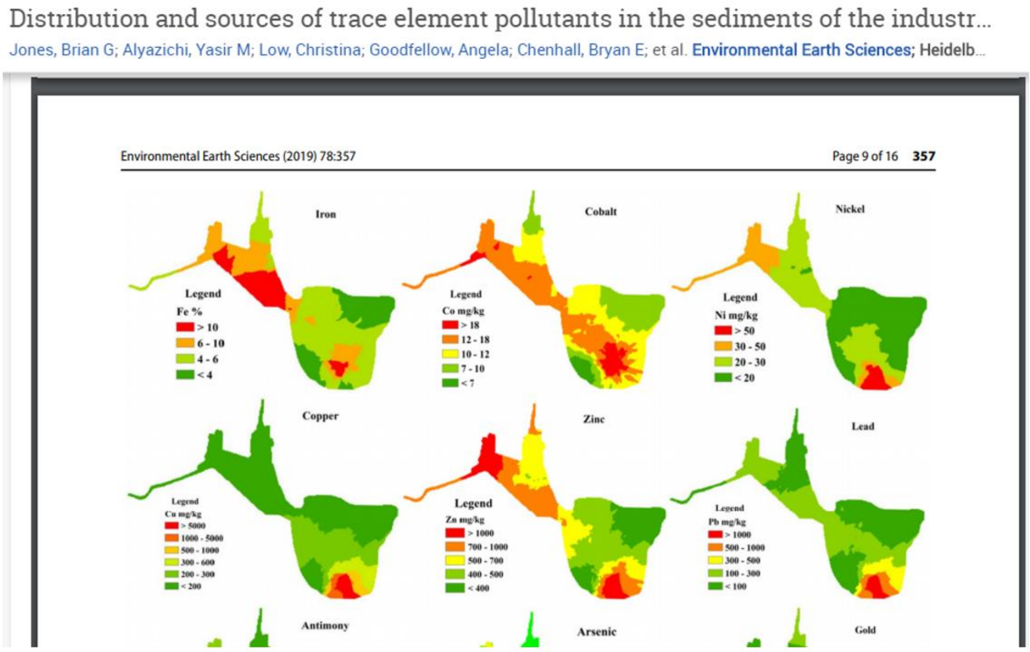
Picture 12: The EPL 3241 100 % concentration limits for LDP 5 discharge to Allans Creek

Recently published results indicate that Port Kembla harbour estuary and Allans Creek has historically very high concentration of several metals (Pictures 13-15; Jones et al. 2019). The data used in this publication by Jones et al. (2019) was published recently but used data collected many years earlier, with the majority of samples collected between 1996-1998. In my opinion, further sediment and water sampling should have been undertaken and reported for this EIS, particularly along Allans Creek, above and below the LDP 5 discharge.

I consider that LDP 5 waste discharges are currently contributing to the pollution of Allans Creek and Port Kembla Harbour estuary. The nature and magnitude of the pollution are currently unknown. Further information on these waste discharges is urgently required. In my opinion, approval of the Project would probably increase the magnitude of the pollution. This is a potentially serious environmental impact from the current Dendrobium Colliery operation that is inadequately addressed in the Project assessment.



Picture 13: Sample locations used by Jones et al. (2019) in their investigation of sediment chemistry iin Port Kembla Harbour. Allans Creek is highlighted.



Picture 14: Summary results by Jones et al. (2019) in their investigation of sediment chemistry in Port Kembla Harbour. See picture 12 for location of Allans Creek.

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ORIGINAL ARTICLE

Check for updates

Distribution and sources of trace element pollutants in the sediments of the industrialised Port Kembla Harbour, New South Wales, Australia

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Abstract
A detailed geochemical analysis of sediment samples from the heavily industrialised Port Kembla Harbour, 70 km south of Sydney in New South Wales, Australia, has delineated areas that are heavily contaminated with trace element pollutants. Local creek delta sand accumulations, basin mud deposits, reclamation deposits and exposed bedrock on the present harbour floor are consistent with the twentieth century Port Kembla industrial land and harbour development history, as well as known maritime shipping practices. The closed electrolytic copper refinery, one of the two major pollutant sources, has provided a very clear signature in the harbour opposite the main drain that discharged from these works. Copper pollution (up to 6070 mg/kg) is strongly correlated with high concentrations of gold, selenium, antimony, arsenic, lead and zinc. These pollutants appear to occur as silt- and sand-sized particulate matter, as well as pollutants that are probably chemically bound to clay, pyrite and organic matter. The second main pollutant source is the BlueScope steelworks that has been responsible for high concentrations of iron (and minor associated cobalt), kish, pyrolytic carbon and fly ash. The steelworks, along with other industrial, urban and automobile sources, supply additional quantities of copper, lead and zinc to the aquatic environment. Coal and coke dust also form important pollutants. The pollutants are currently fairly stable under the prevailing alkaline reducing conditions within the sediment. The proposed future reclamation and dredging within the harbour needs to consider the implications of moving highly contaminated sediment, without altering its alkalinity or oxidation potential, to prevent release of contaminants.

Picture 15: Abstract and details of the sediment contamination study by Jones et al. 2019.

References

ANZECC (Australian and New Zealand Environment and Conservation Council) and ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand). (2000). *Australian and New Zealand guidelines for fresh and marine waters. National Water Quality Management Strategy Paper No. 4.* Australian and New Zealand Environment and Conservation Council/ Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Australian Broadcasting Corporation (2018) Sydney coal mine ordered to repair cracked creek. Available at: (https://www.abc.net.au/news/2018-09-17/sydney-coal-mine-ordered-to-repair-cracked-creek/10253148)

Australian Broadcasting Corporation (2020) South 32 Dendrobium mine disgorges coal sludge into creek. Available at (https://www.abc.net.au/news/2020-08-17/south32-dendrobium-mine-disgorges-coal-sludge-into-creek/12566088)

Belmer and Wright IA (2019) The regulation and impact of eight Australian coal mine waste-water discharges on downstream river water quality: a regional comparison of active versus closed mines. *Water and Environment Journal*

Hannam, P. (2020) Subsidence from coal mine near Sydney leaves creek smashed up. Sydney Morning Herald June 4 2020 Available at: (https://www.smh.com.au/environment/sustainability/subsidence-from-coal-mine-near-sydney-leaves-creek-smashed-up-20200604-p54zjp.html)

Morrison KG, Reynolds JK and Wright IA (2019) Subsidence fracturing of stream channel from longwall coal mining causing upwelling saline groundwater and metal-enriched contamination of surface waterway *Water Air Soil Pollution*

Morrison KG, Reynolds JK, and Wright IA, (2018), Underground coal mining and subsidence, channel fracturing and water pollution: a five-year investigation, Australian Stream Management Conference, pp 689-696,

Price P, and Wright, I.A. (2016) Water quality impact from the discharge of coal mine wastes to receiving streams: comparison of impacts from an active mine with a closed mine, submitted to *Water, Air, and Soil Pollution*, vol 226, no 10

Turner P et al. (2019) Open Letter to the Premier of NSW Regarding Coal Mining in the Schedule 1 Special Areas of the Sydney Drinking Water Catchment. Available at: (https://ssec.org.au/wp-content/uploads/2020/06/Open_letter_to_Premier_re_mining_in_the_Special_Areas.pdf)

Wright IA, McCarthy B, Belmer N, Price P, (2015) Subsidence from an underground coal mine and mine wastewater discharge causing water pollution and degradation of aquatic ecosystems, *Water, Air, and Soil Pollution*, vol 226, no 10

Wright I, Belmer N, Davies P, (2017), Coal mine water pollution and ecological impairment of one of Australia's most 'protected' high conservation-value rivers, *Water, Air, and Soil Pollution*, vol 228, no 3

WaterNSW (2018) Submissions to the Independent Expert Panel on Mining in Sydney Catchment Available at: (https://www.waternsw.com.au/__data/assets/pdf_file/0020/132167/WaterNSW-submission-to-the-IEP-Task-1-of-Terms-of-Reference-vB.pdf)

Qualifications and experience

I am an environmental and water scientist with more than 25 years of experience investigating the impact of human activities on waterways of the Sydney basin. I am currently employed as a Senior Lecturer in the School of Science and Health at Western Sydney University. Earlier in my career I was a freshwater scientist, working in various roles at Sydney Water. This included working as a scientific officer in Sydney Water's scientific laboratories at West Ryde. I then worked as catchment officer in Sydney Water's drinking water catchments. After received my PhD, I was awarded a Postdoctoral Research Fellowship in freshwater ecology and water pollution research at Western Sydney University. Before becoming a fulltime lecturer in 2012, I established a consulting business, mainly helping local Government with projects associated with urban water quality and ecology. I am an advocate for sustainable water and catchment management and I strongly support multi-disciplinary projects. I seek to manage industry problems with evidence-based science. I have specialist scientific expertise in freshwater ecology, water chemistry, pollution ecology of waters, freshwater macroinvertebrates as pollution indicators, impact of urban development, sewage effluent, agricultural, and mine waste impacts on streams and rivers. I have expertise in the sampling design of environmental science studies and statistical analysis of environmental data. I have published (as senior or junior co-author) more than 70 peer-reviewed publications. I have provided independent expert testimonies for environmental science matters for the NSW Land & Environment Court. I am an enthusiastic participant in community engagement activities in my field of expertise.

Qualifications

2006. Doctor of Philosophy, University of Western Sydney.
1995. Master of Science (by research), Macquarie University.
1988. Bachelor of Applied Science (Agriculture), Hawkesbury Agricultural College.

Open Letter to the Premier of NSW Regarding Coal Mining in the Schedule 1 Special Areas of the Sydney Drinking Water Catchment

18/5/20

Dear Premier,

We the undersigned write as concerned academic researchers and scientists to urge an ongoing suspension of the approval processes for any further planning applications or post-approval plans (Subsidence Management Plans and Extraction Plans) for mining in the Schedule 1 Special Areas of the Sydney Drinking Water Catchment. A summary of our reasons for seeking a suspension of mining approvals is attached.

The suspension of approvals should include new projects, the next stage of existing projects and project modifications, and should include proposals and plans currently under consideration. The suspension should remain in place until the now long recognised deficiencies and inadequacies in data gathering and reporting, alert triggers, data and information access, modelling, knowledge and understanding are comprehensively addressed. The suspension should remain in place until the cumulative impacts and consequences of mining to date can be reliably assessed and quantified, with a suitably high degree of scientific confidence. The suspension should remain in place until predictive estimates of the compounding effects of new mining proposals can be made with a suitably high degree of scientific confidence.

In part our letter is compelled by the reports of the Independent Expert Panel for Mining in the Catchment (IEPMC). Adding to those provided to the government since at least 2007, the IEPMC reports reaffirm that the long known and ongoing inadequacies are such that it is not possible to reliably estimate the extent and, accordingly, significance of water losses and water contamination caused by mining in and around the Metropolitan and Woronora Special Areas.

The 2008 Southern Coalfield Inquiry report points out that "*The single most important land use in the Southern Coalfield is as water catchment.*" The importance of accordingly protecting the Special Areas, which lie within the Southern Coalfield, has been emphasised by the recent drought, with low reservoir levels and revelations of high metal contamination levels in the deeper waters of the reservoirs. Among other impact and consequence concerns, the attached summary points to a drinking water loss rate of between 8 and 25 million litres a day as a consequence of mining the Special Areas. Unlikely to be lower, the loss rate could be greater than the range suggested by the available information.

We further encourage the Government to undertake planning for the phase-out of mining in the Metropolitan and Woronora Special Areas. We note that while these areas have been degraded by mining, they still contain some of the few areas of pristine bushland left in NSW. With just two mines currently active, phase out with no further approvals would seem timely.

Please note that this letter, its concerns and recommendation, reflect our personal views as scientists with expertise in hydrology, chemistry, geology and Earth science, environmental and ecosystem science, and public health. The letter is not intended to reflect or represent the institutions and organisations for which we work or are otherwise associated.

Sincerely, Sincerely,

Prof. Allan Chivas	Prof. Simon Chapman	Assoc. Prof. Timothy Cohen
Assoc. Prof. Matthew Currell	Assoc. Prof. Mark Diesendorf	Mr. Pete Dupen
Assoc. Prof. Jason Evans	Dr. Nicolas Flament	Prof. Melissa Haswell
Prof. Grant Hose	Prof. Lesley Hughes	Prof. Stuart Khan
Dr. Tanya Mason	Prof. Graciela Metternicht	Assoc. Prof. Scott Mooney
Assoc. Prof. Gavin Mudd	Assoc. Prof. Patrice Rey	Dr. Peter Turner
Dr. Floris Vanogtrop	Prof. David Waite	Dr. Ian Wright

Open Letter to the Premier of NSW Regarding Coal Mining in the Schedule 1 Special Areas of the Sydney Drinking Water Catchment

Summary of concerns regarding continued mining of the Special Areas

(Additional WaterNSW quote and Fig. 20 added 31/5/20.)

The Schedule 1 Special Areas constitute the core of the Sydney Drinking Water Catchment and may reasonably be regarded as the primary public health asset for more than five million people. The reservoirs in the Metropolitan and Woronora Special Areas are of importance in contributing some 20% of the total supply for Greater Sydney and the Illawarra. Wollongong is notably dependent on the Avon Reservoir.

Underground coal mining in the Special Areas diverts and consumes water at its source, and irreversibly damages and degrades that source. Mining currently takes place in the Metropolitan Special Area and the Woronora Special Area, and the extent of mining in these areas is indicated in Figure 1. Some 166 longwall panels have been extracted from beneath the Special Areas since this extraction technique began to replace bord and pillar methods in the 1960s. Of these, 31 have been extracted to date at the Metropolitan Colliery from July 1995, and 14 extracted at the Dendrobium mine from March 2005. Currently these are the only operational mines extracting coal from the Special Areas, with Russell Vale Colliery in care and maintenance since September 2015 and Wongawilli Colliery closed in April 2019 for safety reasons.

The extent of bord and pillar mining with pillar extraction in the Special Areas, which can cause the same levels of subsidence as longwall extraction, is poorly documented. The long term, intergenerational, stability of the remaining pillars is not known. Evidently triggered by subsequent mining in an underlying seam, pillar collapse has occurred at what is now the Russell Vale Colliery, and instability prevented the mapping of old extraction areas at this mine. While the area is not one of strong seismic activity, the level of faults within the Woronora fault zone is relatively high between the reservoirs (see Fig. 2).

While coal mining returns economic and social benefits in the short to medium term, the damaging and destructive catchment impacts and associated consequences will last into the long-term and indefinite future. We note the August 2013 advice of what was then the Sydney Catchment Authority to its then board:

> "*The people of NSW will benefit from the Metropolitan dams in the short, medium and long terms. The benefit from coal mining is short term extending into the medium term*"

There does not appear to have been an independent and comprehensive assessment of benefit and cost. An assessment of cost would include the likely very substantial cost of comprehensively addressing monitoring inadequacies, in a manner recognising the very high importance of the Special Areas. Mining companies do not currently replace, pay or otherwise provide compensation for the water diverted or lost from the storage reservoirs. Doing so would be confounded by the lack of reliable knowledge of water losses and the possibility of water losses that continue in perpetuity.[1] There would seem to be no prospect for compensation for water that continues to be lost into the decommissioned and abandoned mines. Other than very limited watercourse remediation of uncertain effectiveness and durability[1], the mining companies are not required to provide compensation for the damage to the watercourses and aquifers that supply and support the reservoirs supplying water to Greater Sydney and the Illawarra, and supply and support the biota of the Special Areas. Water treatment costs arising from mining the Special Areas are not known, nor is appropriate compensation for the unknown quantities of contaminants accumulating on and near the floors of the reservoirs. The Special Areas contain some of the few remaining areas of pristine bushland in NSW, including swamp communities listed as endangered under State and Commonwealth legislation. Some 83% of the Coastal Upland Swamp are found on the Woronora Plateau[2] and most are located in the Metropolitan and Woronora Special Areas. There are no known effective means of swamp remediation[1], [3] and ‘like for like’ offsets are difficult if not impossible.[4] The swamps of the Special Areas may accordingly be undervalued.

Impact and consequence concerns include:

- Considerable volumes of water entering some of the mines in the Special Areas, including an unknown quantity of water pooling in decommissioned mines and closed-off sections of mines. Inflows to decommissioned mines or closed-off sections of operational mines are either not known or, where there is monitoring by mine operators, are not reported. Mine inflow monitoring is not audited. Publicly available mining company reports have been used[5] to estimate a daily water inflow volume of 29 to 42 million litres. How much of this would otherwise have entered the storage reservoirs in the Special Areas is not known. A 2018 scoping study[6] undertaken on behalf of WaterNSW has estimated that over the period January 2010 to January 2016, some 43% of the water entering the Dendrobium mine would have otherwise contributed to drinking water supplies. Reflecting connected seam to surface fracturing, inflows to the Dendrobium mine vary with rainfall, with peaks of up to 13 million litres a day. Inflows to the adjoining Wongawilli mine are also rainfall dependent and can be similarly substantial (see below).[7] This may also be the case for some of the closed mines in and around the Special Areas.
- The 2018 scoping study[6] commissioned by WaterNSW suggests the possibility that an average of 25 million litres a day of streamflow may be being diverted and lost from the reservoirs, because of coal mining in the Special areas. Emphasizing the longstanding and long known paucity of monitoring and available records, this estimate of catchment streamflow loss is highly uncertain and, accordingly, unreliable. The study doesn’t include uncertain or unknown losses arising from the depletion of groundwater supply to the reservoirs, nor uncertain or unknown reservoir leakage volumes.
- The Independent Expert Panel for Mining in the Catchment (IEPMC) has suggested[1] up to 8 million litres a day (Ml/d) are diverted from the storage reservoirs as a consequence of mining the Special Areas. Among other limitations, the IEPMC estimate does not include water volumes diverted by decommissioned mines, and it would not be unreasonable to regard the IEPMC

estimate as a lower-bound on the real rate of drinking water loss. Referring to the 2018 WaterNSW scoping study and noting uncertain or unknown losses of groundwater supply to the reservoirs and uncertain or unknown leakage rates, the total loss rate could conceivably be greater than 25 Ml/d. That is, drinking water losses could be between 2.5 and 9 billion litres a year, or more.

- A loss of 25 million litres a day would correspond to some 10% of the maximum daily output of the desalination plant and approximately 8% of the average daily volume of water supply taken in total from the Avon, Cataract, Cordeaux and Woronora Reservoirs. Wollongong and other parts of the Illawarra depend on the Avon Reservoir. Losses would continue for many decades after mine closure and, as the IEPMC points out[1], some of these losses may continue in perpetuity.
- The volume of water accumulated to date in the mines in and around the Special Areas is unknown but substantial, possibly comparable or greater than the water volume held in the reservoirs. The mining companies may have data that would clarify the extent and magnitude of underground pooling and draining. Provided on request by Wollongong Coal, Figure 3 depicts pooling at the Wongawilli mine. The printed text on the graphic states: "A*pproximate potential position of underground ponded water. Note: some water levels dynamic - some areas inaccessible so confirmation of levels not possible*". The handwritten note states "*Water as high as 212 RL on ISG plans*"; it's not known which part of the mine is referred to in this comment. The Nebo area was closed in 2019 for safety reasons. The mine's Community Consultative Committee has been told that its anticipated that when the ponding reaches about 205 RL, water will begin to drain from a portal in the escarpment, near Dombarton. Pooling is known to be occurring at the other mines in and around the Special Areas. Reflecting this, Metropolitan Colliery's in-rush hazard management plan assumes the adjacent Coal Cliff Colliery is entirely flooded. That the mining companies may have valuable data and information is highlighted, for example, in the recommendations of the 2007 report[8] (see Appendix A) and recognised in the 2014 review[9] of cumulative impacts by the NSW Chief Scientist.
- The mining company's consultant estimates[10] that the mining proposed for Areas 5 and 6 of the Dendrobium mine would result in a total average mine inflow rate of 22 million litres a day between 2023 and 2049. This could approximately double the volume of surface water diverted daily from the reservoirs, by this mine.
- Not all surface water and near surface groundwater diverted from otherwise reaching the storage reservoirs by mining impacts necessarily drains to the mine. Surface water and near surface groundwater loss may be also the result of subsurface dilation effects and the creation of subsidence fractures that connect to groundwater flows that leave the catchment area (see Fig. 4).[11], [12] [13] There does not appear to be a means of reliably determining such losses.
- In reviewing the then proposed expansion of the Appin and West Cliff mines in 2010[9], the Planning Assessment Commission (PAC; now the Independent Planning Commission or IPC) made the following observations:

> "*The Panel is of the view that it is no longer a viable proposition for mining to cause more than negligible damage to pristine or near-pristine waterways in drinking water catchments or where these waterways are elements of significant conservation areas or significant river systems*."

And

> "*The Panel finds that the exclusion of first and second order streams from consideration of consequences ignores the vital role that these streams play in the interconnectivity of the system. In particular they are important in protecting the continuity of flow and the quality of water conveyed between the upland swamps and the larger streams*."

Subsequent approvals have impacted pristine, near pristine and previously damaged waterways. There does not appear to be a publicly available map recording the mining damaged lengths of streams, of all orders, in the Special Areas.

- Mining induced surface fracturing (see Figs. 5 and 6) may extend to considerably greater depths than has been suggested by mining company consultants.
- The injection of a curtain of barrier material, such as polyurethane resin (PUR; see Fig. 7), as a means of remediating impacted watercourses may be of limited effectiveness[1], [4], [14], particularly during periods of low flow. A 2013 tracer study of impacts to Waratah Rivulet undertaken by Parsons-Brinckerhoff[12] and commissioned by WaterNSW (then the Sydney Catchment Authority) comments on the failure of injected tracer to return to the surface downstream:

> "*Extensive remediation works involving the injection of PUR into fractures has been undertaken since 2008 in the vicinity of the injection bore, which may have caused some retardation of the tracer. However, it is also hypothesised that the tracer has moved through subsurface fractures not connected to the surface water system, but are possibly connected to the deeper Hawkesbury Sandstone*."

When subsurface water reaches the barrier, some is deflected to the surface. Some, however, may be deflected away from the watercourse in a manner depending on the nature and extent of the surface fracture network. The PAC report for the Metropolitan Colliery expansion comments that "*Polyurethane injection also penetrates natural sub-surface flow networks and so may not fully restore the natural environment*."[2] That is, the blockage of natural flow paths may divert subsurface flows away from the pre-mining path, with the possibility of loss from the local catchment.

Barrier injection is only feasible in reasonably accessible and favourable locations. The damning effect of barrier injection does not redress a mining-induced water table reduction and consequential loss of stream baseflow from supporting aquifers. Understanding the influence a barrier has on surface and subsurface waters would require comprehensive pre- and post-mining flow, groundwater pressure data and detailed tracer studies. Such work does not appear to have been undertaken.

- The 2010 PAC review[9] of the then proposed expansion of the Appin and West Cliff mines reports:

  "*Studies have also revealed that upsidence extends some tens of metres beneath valley sides and does not necessarily follow the line of a watercourse. Rather, it can cut across valley headlands and bends in a watercourse.*"

- Subsidence induced dilation and fracturing can increase near surface groundwater flow rates from 50 m/day[12] to 4,800 m/day.[15]
- Where surface water diverted into subsidence cracks does return to the surface further down-stream, it may be with groundwater that would not otherwise have joined surface flows. This may 'mask' net water loss, where losses are assessed using only downstream flow gauges.[1], [13]
- There remains uncertainty with respect to the accuracy, precision and calibration of flow gauges, especially those where a natural rock profile is used. Measuring low flow and differentiating baseflow contributions in the Special Areas in order to discern mining impacts, is challenging. In addition, the number of gauges does not appear to be sufficient to reliably characterise the watercourse responses to mining of the Special Area catchments.
- Water loss becomes increasingly significant during low rainfall periods and such periods are expected to increase as climate change progresses.
- There is accumulating evidence that the drainage zone, the zone of connected fractures that forms over a coal extraction (see Figs. 8 to 10), reaches the surface above parts of the Dendrobium mine (Figs. 11 to 13), or gets close enough to join the surface fracture network. This was predicted in 2012 in a set of pre-mining impact assessment reports[16]–[19] commissioned and then rejected by the mine operator. Following concerns raised with the Minister in July 2015[20], [21], a more detailed review[5] of the publicly available data provided to the Minister and Department of Planning in December 2016, found the data consistent with the 2012 drainage zone height estimates. This is affirmed in the mine's most recent extraction impact assessment report.[22] Where the drainage zone reaches the surface, rainfall and other surface water drain relatively rapidly to the mine below. Mining induced depletion of the aquifer that provides groundwater to the reservoirs, watercourses and swamps is maximised. The greater the height of the drainage zone, the greater the rate and spread of aquifer depletion; horizontal depletion occurs between 10 and 1,000 times more rapidly than vertical depletion. The drainage zones over each longwall extraction at the Dendrobium mine are 305 metres wide, on average some two kilometres long, and appear likely to either reach the surface or approach the surface. Adjacent drainage zones will partially merge to form an extended zone over the mining area that draws water towards and into the mine. Aquifer depletion continues to spread outwards from the mine area for as long as water is

pumped from the mine, until pumping stops and the mine is sealed and then fills. As the IEPMC points out, water removal at Dendrobium may need to be continued indefinitely (see below).[1] This may also be the case for the Wongawilli mine (see below).

- Large voids created by total pillar extraction in some of the old mines in and around the Special Areas may also have resulted in the drainage zone approaching or reaching the catchment surface. This may, at least in part, be the reason for the rainfall dependence of inflows at the Wongawilli mine, which vary between 4.3 and 10.4 million litres a day.[7]
- The 2010 groundwater impact assessment for the 2010 longwall mining proposal for the Nebo area of the Wongawilli mine reports:

  > "*bord and pillar as well as pillar extraction and longwall mining has been conducted in the adjacent Wongawilli, Elouera and Dendrobium Area 2 workings, and that vertical hydraulic connection has been observed at some locations between surface streams and the underlying workings*".[23]

  The assessment report further comments that a significant but unquantified component of the water entering the Elouera mine comes "*from surface water seeping through subsidence cracks following extraction of Elouera Longwalls 6 and 7 under Wongawilli Creek*" (see Fig. 5).[23] That is, the longwall mining evidently resulted in a direct hydraulic connection from mine to the watercourse. What was the Elouera Colliery is now part of the Wongawilli mine. As mentioned above, the mine is expected to drain from the escarpment.
- Pillar collapse, as appears to have occurred[24] at what is now the Russell Vale mine, might also result in seam to surface connected fracturing.
- Above the Metropolitan Colliery's longwall extractions, notably low pre-expansion project groundwater pressure in the aquifer that supplies groundwater to Woronora Reservoir is attributed[25], at least in part, to the mine's old extraction area to the east and to closed mines to the south. Full pillar extraction was employed in these mining areas. The extraction details are not publicly available, however it would be reasonable to assume on the basis of the groundwater decline, that this mining will have resulted in large voids and correspondingly substantial drainage zones. There may be connected seam to surface fractures. The Metropolitan mine's longwall expansion project commenced in 2010 and appears to have significantly exacerbated the prior aquifer depletion.[26]
- Reflecting a lack of monitoring installations, there is no knowledge of the extent of the drainage zone formed over multi-seam extractions. Multi-seam extractions have taken place at the Russell Vale and Wongawilli mines. The drainage zone may have reached the surface over some of these extractions.
- As indicated above, estimates of the height of the drainage zone emerged as an issue of significance in 2015.[21] Pre-mining centreline bores are not essential in seeking to determine the relationship between mining geometry and the height of the drainage zone. That is building on the

current limited database of mining geometries and drainage zone heights would not require new mining. As recommended to the Minister and Department in 2015 and 2016[5], [20], a program of post-mining centreline bores above past approval extractions, including multi-seam extractions, would be sufficient. For example, in 2012 Tahmoor Mine commissioned a drilling and investigation program above the centre of Longwall 10A, which had been mined approximately two decades earlier.[27] Centreline bores sunk in areas of high horizontal stress may give anomalous results.[28]

- Mining within the vicinity of the storage reservoirs can cause stored water loss into shear planes that may either facilitate diversion to the mine or take water away from the catchment (see appended Figs. 8 and 18). Shear plane leakage is known to have occurred at the Cataract[29] and Avon reservoirs[30], and appears to have occurred at Cordeaux reservoir.[31] Evidence of shear plane transport has been found 540 metres from Cataract Reservoir.[32] The available data suggest that leakage from Avon reservoir may exceed the tolerable loss limit of the Dams Safety Committee.[33] There is insufficient monitoring to determine whether or not this might also be the case for the other reservoirs. A 2017 recommendation by consultants PSM to follow-up leakage evidence at Cordeaux Reservoir does not appear to have been acted upon.[1], [5], [31]
- A 2014 paper[29] by the Dams Safety Committee reports evidence of shear plane leakage from Cataract Reservoir, following mining below and near the reservoir (see Fig. 14). Presumably a consequence of mining below the reservoir and having implications for mining below Woronora Reservoir, the study also found that subsidence movements continued, with reactivation, for 25 years after completion of the mining. This is much longer than found elsewhere in the Special Areas and may be a consequence of mining below the reservoir. The impacts and consequences of the subsidence continue indefinitely.
- The mining at Cataract Reservoir resulted in the dam wall moving some 3 centimetres, as a consequence of shear plane movements.[9], [14] The ‘en masse’ nature of the land movement did not result in damage, but that movement of this kind can occur gives cause for concern. The mining was some 800 metres from the dam wall.
- Valley bulging can create leakage pathways around and below reservoirs and watercourses, as reported in the 2017 Dendrobium study[31] by consultancy PSM. Though considerably more conservative in character than the mining at Dendrobium, the recently approved mining below Woronora Reservoir (see Fig.15) may result in valley bulging, shear plane activation, geological anomalies and subsidence fractures formed at the base of the reservoir and water being lost from the reservoir and, bypassing the mine, the local area catchment (see Fig. 16).[1] Mining below Woronora Reservoir has been approved without a robust means of reliably estimating consequential water losses, other than monitoring inflow to the mine.
- Currently it is not possible to develop reservoir water balance models (see Fig. 17) for any of the reservoirs, with sufficient accuracy and precision to be able to reliably gauge the magnitude and

significance of water losses caused by mining. There is then the possibility that more than negligible losses may occur without detection.

- Watercourses can change from being groundwater gaining to being water losing, as a consequence of mining induced groundwater drainage and loss (see Fig. 18). This appears to have happened to watercourses over and near the mining in both the Metropolitan and Woronora Special Areas. This includes sections of Waratah Rivulet[11], [12], Wongawilli Creek tributary WC21[22], [34], Wongawilli Creek[22], [34], and possibly sections of WC15 and Eastern Tributary.
- There is ongoing and increasing depletion across the Special Areas of groundwater in the aquifer that provides inflow to the storage reservoirs. Groundwater inflow to the reservoirs has heightened importance during dry and drought periods. The Dendrobium mine (Fig. 11) appears likely to have added considerably to the significant and extensive aquifer depletion between the Avon and Cordeaux Reservoirs, caused by past mining beneath and around the Metropolitan Special Area. The Department of Planning was advised in December 2016[5] that the available data from the Dendrobium mine suggested the possibility of significant depletion of the aquifer providing groundwater to the Avon and Cordeaux reservoirs. Significant depressurisation is reflected, for example, in alert trigger exceedances at a set of four reference bores (TARP sites). The PSM report[31] of March 2017 similarly finds extensive depressurisation, from a different perspective. Approval conditions for the Dendrobium mine require no more than a negligible reduction in groundwater flow to the Avon and Cordeaux. The limited available data point to the possibility that the mine may have caused a more negligible reduction in groundwater support for the Avon and Cordeaux reservoirs. There would appear to be insufficient monitoring sites, however, to be able to unequivocally determine whether or not this is the case.
- The available monitoring data[35] suggest that mining, both before and since the 2010 commencement of the current Metropolitan mine expansion project, has caused a considerable depletion of groundwater in the aquifer that supports Woronora Reservoir.[26] Approval conditions for the Metropolitan mine require no more than a negligible reduction water resources, which would include groundwater, reaching the Woronora Reservoir. The limited available data raise concern that mining will, if not already, cause a more than a negligible reduction in groundwater support for the reservoir. There would appear to be insufficient monitoring sites to be able to unequivocally determine whether or not this is the case.
- Unequivocally establishing a more than negligible change to groundwater flow to the reservoirs, to the satisfaction of all, would require a network of piezometer bores placed some 300 to 400 metres apart around the flanks of the reservoirs nearest the mining. A similar network would be required along watercourses, to establish groundwater support changes. Such bores would need to be sunk at least two years in advance of new mining.

- The appended 2007 McNally and Evans report recommends baseline data for new or proposed mining areas up to 20 years ahead of mining. Areas 5 and 6 of the Dendrobium mine are examples of proposed new mining areas.
- The ongoing depletion of groundwater risks a 'tipping point', where a reservoir changes from being groundwater gaining to losing water into the groundwater system, this would compound any leakage pathways that might be created through direct subsidence impacts when a reservoir is undermined. While that point might not be reached during periods of good rainfall and 'recharge', it might be passed during extended dry or drought conditions.
- A groundwater system depleted by mining would generally be expected to recover, after many decades, following mine closure and sealing. This will not be the case where the drainage zone reaches the surface, as at Dendrobium, and pumping is continued indefinitely to prevent contaminated water being discharged at the catchment surface (also see below).[1], [5] Ongoing pumping will increase and spread aquifer depletion. In some cases it may not be possible to seal adits or other leakage points, in which case mine drainage could continue indefinitely.[1]
- Allowing the drainage zone to reach the aquifer supplying water to the reservoirs and to further allow it to reach the surface, is inconsistent with the intent of the Special Areas. Highlighting this perspective, in seeking to protect the catchment used for Central Coast Water Supply, the approval conditions set by the Planning Assessment Commission (now the IPC) for the Wallarah-2 project, required "*No connective cracking between the surface, or the base of the alluvium, and the underground workings*". That is, that the drainage zone should not approach or reach the catchment surface. The Wallarah-2 project presents potentially adverse consequences for the Central Coast drinking water catchment. WaterNSW unsuccessfully sought the same protection for the Special Areas in comments submitted to the Department of Planning in February 2018, on the then proposed mining plan for Longwall 16 at the Dendrobium mine. Longwall 16, 17 and 21 have, however, been approved with the drainage zone of each approaching or reaching the catchment surface.
- Dendrobium Area 3B Longwalls 9 to 13 were approved in a controversial manner[21] in February 2013, with total extraction widths of 305 metres and heights of up to 3.9 metres for Longwall 9 and up to 4.6 metres for Longwalls 10 to 13. The mining company sought approval for extraction heights of 4.6 metres for Longwalls 14 to 18 in July 2015. Longwalls 14 and 15 were approved in December 2016, with extraction heights of up to 3.9 metres. The Department characterises its approval of Longwalls 14 and 15 as "*precautionary*" and 3.9 metres as "*substantially less"* than 4.6 metres. As Figure 11 below indicates, the 15% height reduction is actually relatively small. Figure 12 indicates that the height reduction is of limited consequence, with the drainage zone nonetheless either reaching the surface or getting sufficiently close to join the surface fracture network. From this perspective, it is difficult to regard the approval as precautionary. Suggesting mining as the leading consideration, the approval notes the following:

> "*the width of panels would need to be narrowed by more than 40% to significantly reduce the environmental impacts to key surface features. This is not considered economically feasible*"

Longwalls 16 and 17 have subsequently likewise been approved with total widths of 305 metres extraction heights of up to 3.9 metres. A reduction of 40% would correspond to a width of 122 metres, which is similar to the width of Wollongong Coal's Nebo panels at the neighbouring Wongawilli coal mine. At up to 3.6 metres, the extraction height at Wongawilli is less than at the Dendrobium mine. Wollongong coal ceased operations in the Nebo area in 2019 because of concerns.

- Consultants GeoTerra indirectly advise[36], [37] that the drainage zone doesn't need to reach the surface to exert an adverse influence:

  > "*A minimum thickness of unfractured overburden is required to maintain hydraulic separation between a mine and saturated aquifers, with the critical value depending on lithology, structure and topography. The minimum separation has been established through observation and research in NSW mines as ranging from less than 90m up to 150m*."

  This observation would also suggest that drainage zones should not reach an elevation greater than 90 to 150 metres below the elevation of a nearby reservoir.

- Unexpectedly severe impacts to swamps and watercourses have been found above the Dendrobium mine, notably at Wongawilli Creek tributaries WC21 and WC15. WaterNSW has expressed concern that the impacts to Wongawilli Creek have exceeded mining approval conditions. In part at least, the catchment damage reflects the notably aggressive nature of the mining at Dendrobium. As the IEPMC observes[1], establishing a breach of approval conditions is very difficult, if not impossible, because of the nature of those conditions. In its December 2019 comments[38] on the then proposed mining plan (SMP) for Longwall 21 in Area 3C, subsequently approved in March, in Area 3C of the mine, the IEPMC observes as follows:

  > "*The SMP states "The rate of impacts along Wongawilli Creek due to the previous mining [at Area 3B and Area 3A] is considered to be very low".[6] As raised in the Panel's Part 2 Report, this is not a generally accepted position. In particular, WaterNSW has questioned whether the performance measure relating to minor impacts to Wongawilli Creek has already been breached. This is a fundamental problem of the suitability of the performance measures, as discussed in the Part 2 Report, and not easily resolved within the current approval consent.[7]*"

  Compounding this difficultly, monitoring is inadequate relative to the scale of the mining. In this highly unsatisfactory context, the agencies and/or community would need to establish beyond reasonable doubt, to the satisfaction of all stakeholders, that an approval condition for mining the Special Areas has been breached. As the IEPMC comments imply, this is difficult, if not impossible.

- In its May 2018 comments[39] on the then proposed Longwall 16 mining plan, approved later that month by the Department of Planning, WaterNSW accepts that there is a lack of unequivocal evidence that the approval conditions for the mining had been breached, but points out the following:

> "*There is however significant circumstantial evidence (e.g. the anomalous piezometric response next to Cordeaux Reservoir, the rapid and sustained drying of a discrete stretch of Wongawilli Ck adjacent to an unexpectedly drained zone of Hawkesbury Sandstone aquifer and other anomalies recorded for Wongawilli Ck flows and water quality, and the sustained drying of streams SC10C, Donalds Castle Ck and WC21) that suggests that they might have and/or that they will in the near future.*"

The approval of Longwall 16, and subsequently Longwalls 17 and 21, reinforces concerns of the benefit of doubt being given to mining in the absence of adequate monitoring, data, knowledge and understanding.

Groundwater monitoring sites at Dendrobium mine report large drawdowns[5] in the aquifer that supports the Avon and Cordeaux reservoirs, suggesting the possibility of a more than negligible reduction in groundwater support for the reservoirs. In the absence of sufficient monitoring installations, it is not possible to unequivocally determine whether or not it is likely that there has been a more than negligible reduction in groundwater supply to the reservoirs.

- The 2008 Southern Coalfield Inquiry recommended a '*reverse onus of proof*' whereby a mining company would be required to demonstrate that natural features identified as being of high significance would not be unacceptably impacted. In 2009 the NSW Planning Assessment Commission stepped back[6][11] from that recommendation, expressing the view that requiring a reverse onus of proof would be unreasonable and likely impossible for companies to provide, given the lack of data and inadequate understanding: "*Given the knowledge gaps in the relationships between subsidence impacts and consequences for natural features, and the poor databases for many key features in the region, this would effectively put the Proponent in the position of trying to prove the unprovable.*" A mining project proponent is instead required to demonstrate the reasonableness (or overall merit) of its proposal in relation to the significant natural features that may be exposed to subsidence impacts. The uncertainty and benefit of doubt inherent in accordingly approving projects in a context of significant data, knowledge and understanding gaps, is manifested in the unexpected impacts and consequences at the Dendrobium and Metropolitan mines.

  Mining may be approved and its performance assessed on a basis of argument from ignorance. The absence of strong evidence does not, however, necessarily mean that significant consequences do not exist or will not occur, particularly in a context of inadequate monitoring, and limited data and information availability. Given the importance of the Special Areas, where limited data point to the possibility of a significant impact consequence, it would seem reasonable to assume that this has occurred or will occur, until reliably established otherwise with scientific confidence.

- Other than circumstances where the evidence is immediate and overwhelming, the onus of unequivocally establishing a likelihood of unacceptable impact and consequence occurring, or having occurred, rests with the agencies, NGOs and the community, in the same context of inadequate data, knowledge, modelling and understanding recognised by the Planning Assessment Commission in stepping back from requiring a reverse onus of proof. These limitations are compounded by lack of access to data, reports and other information held by mining companies. The Dendrobium mine revelations that triggered the sequence of investigations[31], [42] that culminated in the formation of the IEPMC, came from the community in a context of inadequate and refused access to information.[21], [42]
- Compounding the problem of monitoring systems and networks remaining inadequate relative to the scale and complexity of mining impacts and consequences in the Special Areas, failed groundwater instruments are typically not replaced. Where instruments are replaced, the replacement may not be equivalent. As a consequence, for example, it's not possible to reliably determine the height of the drainage zones over Longwalls 302 and 22B at the Metropolitan Colliery.[26] There is insufficient data to be able to quantify mining impacts and consequences with high scientific confidence.
- There is limited ability to model and predict rainfall infiltration and sub-surface recharge, runoff diversion, valley closure and valley bulging effects, shear plane effects, local geology interactions and the effects of geological anomalies/discontinuities (faults, dykes, intrusions).
- Subsidence and groundwater and surface water responses can be significantly underestimated in the vicinity of lineaments. Comparatively modest mining at the Metropolitan Colliery has nonetheless resulted in unexpectedly severe impacts to Waratah Rivulet and Eastern Tributary. Impacts to Eastern Tributary exceeded the approval conditions for the mining. Anomalous geological interactions may also be contributing to the notable depletion of groundwater suggested by the (limited) monitoring[35] in the aquifer supplying groundwater to Woronora Reservoir. There is no means of reliably predicting the outcome of mining in unusual or inadequately understood geological settings.
- In its March 2019 submission[40] to the IEPMC, WaterNSW provided the following recommendation:

  > "*Given the uncertainty associated with predictions of environmental consequences, WaterNSW considers a precautionary approach to the assessment and determination of mining proposals within the Special Areas is warranted. There must be a high degree of confidence that any proposed mining does not exceed key predictions or performance measures in development consents, Subsidence Management Plans (SMPs) and Extraction Plans. On that basis, no further approvals should be given for mining that would permit the level of environmental impacts and consequences that have occurred in Wongawilli Creek, WC21, and Swamps 1a, 1b and 5 at Dendrobium, and Waratah Rivulet and Eastern Tributary at Metropolitan.*"

Notwithstanding modest mining practices, Waratah Rivulet and Eastern Tributary have suffered unexpectedly severe impacts above Metropolitan Colliery. There is currently no means of predicting such impacts.

- Surface water and near-surface groundwater contamination by mining induced ‘iron springs’ (see Fig. 19). Water flowing over subsidence induced fractures dissolves minerals to contaminate both surface water inflows to the reservoirs and groundwater inflows from the aquifer that supplies groundwater to the reservoirs. Groundwater may also be contaminated by shear plane activation and iron spring activity may be triggered some distance from the mine area.[14] As highlighted in the media in December 2019[43], the ongoing accumulation of tonnes of metal containing contaminants on the floors of the reservoirs, becomes evident as reservoir levels fall during drought. The SCA (now WaterNSW) estimated that between February 2002 and August 2009 some 15 tonnes of iron and 4 tonnes of manganese were added into Woronora Reservoir from the mining impacted Waratah Rivulet.[44] The agency’s estimate February 2002 to June 2011 is 19 and 5 tonnes respectively.[45] These estimates would not include the additional loading from contaminated groundwater inflow to the reservoirs. Iron springs remain active for decades. The total iron spring derived contaminant loading on and near the floors of the reservoirs is not known; an assessment program that includes core samples from the reservoir floors would seem to be required. Mining under Woronora Reservoir may cause further loading via subsidence cracking of the reservoir floor.
- The Department of Planning Director General’s June 2009 environmental assessment report[115] for the then proposed expansion of the Metropolitan Colliery describes iron spring activity along the Waratah Rivulet, initiated as a result of the mine’s first longwall mining project:

  > “*Large areas of rocky substrate in the Waratah Rivulet and other watercourses have been observed to be covered by orange-red iron staining for many hundreds of metres downstream of mine subsidence fractures. If the iron concentration is sufficiently high, and the aquatic environment is suitable, then orange, bacterially-based iron flocs may also form in ponds. Potential ecological effects of such flocs are reported to include smothering of benthic habitat and biota and reduced light available for aquatic plants. Bacterially-catalysed oxidation of iron also consumes dissolved oxygen from the water column*.”

  The expansion project was subsequently approved.
- The 2010 PAC review[9] of the then proposed expansion of the Appin and West Cliff mines, has the following observations:

  > “*the consequences of iron staining, opacity, bacterial mats and deterioration of water quality has potentially significant consequences for hydrologic values (water quality), ecological values, environmental quality and amenity value*”.

- Anecdotal reports suggest that the mine workings in the Special Areas can be located from the air by the distribution of stream discolouration caused by iron springs above and around the mines below. The report for a 2013 workshop organised by the SCA[46] comments:

  "*One participant noted that when flying over the Southern Coalfield, the mining impacts on streams were clearly visible, and water discoloration due to iron precipitates in water travelling through new subsurface flow paths and re-entering streams could be used to map the extent of underground workings*"

- The 2010[14] review by the Planning Assessment Commission of the then proposed expansion of the Appin and West Cliff mines has the following observation: *"Isolated stain occurrences located in the upper reaches of O'Hare's Creek and Woronora River are remote from existing mining, but may still be associated with far field movements of the rock strata*". The use of Woronora River as a control for mining induced iron spring contamination of Waratah Rivulet is likewise questionable.[47]
- Allowing catchment water to be degraded on the basis of subsequent treatment contradicts best practice public health risk management and the intent of the Special Areas. Treatment adds to the environmental and economic costs of water supply.
- Where the drainage zone reaches the surface, there will be contaminated water discharges onto the catchment when closed mines fill with water (see Fig. 20).[5], [48] As pointed out by the IEPMC[1], and noted above, avoiding this problem will require the ongoing removal of water from the mine, in perpetuity. The Department of Planning subsequently approved the extraction of Longwall 21, which may again result in the drainage zone joining the surface fracture network, if not reaching the surface.
- Ongoing degradation and loss of the upland swamps (see Fig. 21) through bedrock cracking with linkage to drainage pathways. Reduced bushfire resistance and catchment resilience to drought is eroded through the loss of runoff filtering and moderation capacity. There are no known effective means of swamp remediation.[1], [3] These concerns are compounded by inapropriate swamp loss offsets. Commenting on offsets for damage to swamps over the Dendrobium mine, WaterNSW points out the following[4]:

  "*The proposed biodiversity offsets for swamps are not within WaterNSW's Special Areas or the Sydney drinking water catchment and therefore would not result in any compensatory effect in the water quality, water quantity, aquatic ecosystem or ecological integrity of these resources*."

- Biota and biodiversity loss, including threatened species.
- Methane migration towards and emission from the land and water over the mines. Methane is a much more potent greenhouse gas than is carbon dioxide; it breaks down to form carbon dioxide in the upper atmosphere.

- Notwithstanding the concerns and recommendations of past reports to government (see below), the ongoing lack of transparency and access to data, reports and other information held by mining companies continues to hinder or prevent independent assessment of the impacts and consequences of mining the Special Areas. For example, in their 2017 report on impacts over the Dendrobium mine, consultants PSM note limited data access, with some not being provided notwithstanding repeated requests.[31], [49] Government agency approval of the release of mining company provided reports and information on impacts to the Special Areas, may be nonetheless be opposed by the relevant mining company. The 2014 Chief Scientist's report on cumulative impacts notes the problem of the agencies having limited access to data and information held by the mining companies:

  > "*The problems that the Sydney Catchment Authority has accessing data from companies using the Special Areas was noted, as was the nature of the data that may be held by the companies as well as by government agencies and universities. A contrast was drawn to Alberta, Canada, where any information on public assets must be made publicly available. It was noted that there are no international examples of longwall mining operating in publicly owned drinking water catchments but there are examples of it occurring under streams and aquifers connected to privately owned wells in the Appalachians of the U.S.A.*"

  It would appear that commercial interests continue to be placed ahead of the public interest in the Schedule 1 Special Areas. Further illustrating this, and counter to the practice of science, impact assessment reports commissioned by mining companies often refer to reports withheld by the mining companies. This practice also hinders accountability.

- The calibre of the detailed and informative work[16]–[19] that predicted and modelled the drainage zones at the Dendrobium mine reaching the catchment surface is captured in the comments of WaterNSW (then the SCA) at that time, characterising the work as "*sound and well researched and provides an important step in the development of a rigorous regional groundwater model. The study provides details on estimated groundwater recharge, discusses a new concept of ground deformation and its impact on groundwater hydrology, and applies more constrained ,calibration approach using hydraulic heads, baseflow to rivers, inflows to Dendrobium and other mines) and probabilistic analysis*." As the quote notes, a significant and still distinguishing[38] aspect of this work was its simultaneous calibration with respect to what would appear to be, in the context of limited monitoring and assessment installations, comprehensive sets of groundwater pressure data, hydraulic conductivity data and regional mine inflow volumes. The calibre of this now dated but nonetheless notably informative work remains outstanding. Commercial in confidence privileges are such that it would not be possible to independently update this pioneering work.

- Compounding the problem of lack of access to data and information, is a dependence on assessment reports prepared by consultants selected and funded by mining companies. Such reports cannot be regarded as independent and nor are reviews of these reports undertaken by consultants dependent on subsequent engagement by mining companies. The consequences of incorrect and misleading information provided by consultants and accepted by authorities in a context of scientific uncertainty, have been highlighted in a recent publication addressing the Carmichael Mine and potential impacts to Doongmabulla Springs.[50], [51] Trading under different names, a consultancy referred to in that publication appears to have provided inadequate, flawed or misleading advice on behalf of a number of mining proposals and projects in NSW, including in the Special Areas.[4], [5], [14], [38], [50]–[53] Following initial concerns raised in July 2015[20] and April 2016[4], the Department of Planning was advised[5] in some detail in December 2016 that the groundwater pressure data from the Dendrobium mine appear to have been misinterpreted or misrepresented over a number of years by this consultancy. This was, in effect, affirmed in the PSM report[31] of March 2017. The same consultancy has contributed to impact assessments for the Metropolitan Colliery, including that for Longwalls 305-307.[25] In reviewing the then proposed expansion of the Appin and West Cliff mines in 2010[14], the Planning Assessment Commission made the following recommendation with respect to peer reviews:

> "*15.3.4. Recommendation*
>
> *The Panel recommends that the Department look at this issue with a view to determining whether independent selection and briefing of reviewers should be the norm, even if the cost were borne by the Proponent. As it currently stands the system appears to have little credibility.*"

Directly applicable also to consultants undertaking assessments on behalf of mining companies, the recommendation has not been taken-up. A means to decouple consultant engagement from the proponent is suggested by the funding mechanism for the Mine Subsidence Board, together with random selection from a pool of accredited consultants. While bias would not be eliminated, it should be lessened. De-coupling would also provide an opportunity to remove the commercial in confidence obstacle to data and information access.

- WaterNSW may be insufficiently resourced relative to the scale and complexity of the impacts and consequences arising from mining the Special Areas. This may also be the case for the Department of Planning.

The IEPMC reviews[1], [54] follow, among others, the 2017 PSM[31] review of impacts at the Dendrobium mine and the Galvin[55] and Mackie[56] reviews of that work[57], the 2016 Audit of the Sydney Drinking Water Catchment[58] and prior triennial audits, the 2014 report[9] from the NSW Chief Scientist on cumulative impacts in the Sydney catchment, the 2014 Davey et. al.[3] and Tammetta[59] swamp impact reviews, the 2012 OEH review[60] of impacts at the Dendrobium mine, the 2010 PAC review[14] of the then proposed expansion of the Appin and West Cliff mines, the 2009 PAC review[41] of the Metropolitan Coal Project, the 2008 Southern Coalfield Inquiry[61], the 2007

Krogh review[62] and the 2007 McNally and Evans Southern Coalfield impacts report[8] prepared for the then NSW Department of the Environment and Climate Change.

These reports and references therein document the nature and possible extent of the damage caused by mining beneath the Special Areas and, repeatedly, point to the data, modelling, transparency, balance, knowledge and understanding inadequacies and uncertainties under which mining has been approved and allowed to proceed. The inadequacies and uncertainties are such that it is still not possible to reliably gauge the magnitude, extent and significance of the impact and consequences of mining in the Schedule 1 Special Areas. There continues to be no timetable nor direction to funding to address these longstanding problems.

The ongoing level of ignorance with which mining is approved and undertaken, highlighted by unexpected impacts and consequences at the Dendrobium and Metropolitan mines, urges the suspension of the approvals process for coal mining in the Schedule 1 Special Areas. The suspension should remain in place until deficiencies in data gathering and reporting, data and information access, modelling, knowledge and understanding are comprehensively addressed, such that cumulative impacts to date can be reliably and openly assessed, and quantitative predictions of the compounding effects of new mining proposals can be made with a high degree of scientific confidence. Assessments and predictions should be capable of reliably determining whether or not proposed mining will have a neutral or an adverse effect on the Special Areas, from commencement and into the intergenerational future. As the 2008 report of the Southern Coalfield Inquiry points out, “*The single most important land use in the Southern Coalfield is as water catchment*.”[61]

Appendix A. Recommendations of the 2007 McNally and Evans Southern Coalfield impacts report[8]

1. As a first step towards developing an improved water monitoring system for the Southern Coalfield, the existing fragmented one should be carefully examined. This would involve collation and analysis of information presently held by the Department of Primary Industry, the Sydney Catchment Authority, the Dams Safety Committee and the mining companies themselves, especially BHP Billiton. The aim would be present a regional view of surface and groundwater distribution, flow and quality throughout the coalfield.
2. Plan and implement an upgraded network of observation bores, water sampling points and gauging stations. Such a network would primarily be directed towards:
    - Investigating surface-groundwater interaction, flow and water quality in shallow sandstone aquifers, stream beds and upland swamps.
    - Providing baseline data for new or proposed mining areas up to 20 years ahead of mining.
    - Providing post-mining assessments of water in and around closed mines, the extent of natural remediation and potential groundwater hazards.
    - Devising consistent and cost-effective monitoring and sampling techniques for both groundwater and surface water.
    - Performing numerical modelling of surface and groundwater as required.

Appendix B. Recommendations of the 2014 NSW Chief Scientists cumulative impacts report[9]

Recommendation 1: *That Government create a whole-of-Catchment data repository.*

Recommendation 2: *That Government develop a whole-of-Catchment environmental monitoring system.*

Recommendation 3: *That Government commission computational models which can be used to assess the impacts on quantity and quality of surface water and groundwater.*

Recommendation 4: *That Government encourage the use of data visualisation tools for examining 3D representations of the Catchment.*

Recommendation 5: *That Government establish an expert group to provide ongoing advice on cumulative impacts in the Catchment.*

References

[1] Independent Expert Panel for Mining in the Catchment (IEPMC), ‘Report of the Independent Expert Panel for Mining in the Catchment: Part 2. Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment.’, Office of the Chief Scientist & Engineer, Oct. 2019.

[2] NSW Scientific Committee, ‘Coastal Upland Swamp in the Sydney Basin Bioregion - endangered ecological community listing’, Mar. 2012. http://www.environment.nsw.gov.au/determinations/coastaluplandswampfd.htm (accessed Sep. 03, 2016).

[3] Davey, E.K., Glamore, W.C., and Smith, G.P., ‘Temperate Highland Peat Swamps on Sandstone: evaluation of mitigation and remediation techniques’. Water Research Laboratory, University of New South Wales, Knowledge Report for the Department of the Environment, Commonwealth of Australia., Aug. 2014.

[4] Water NSW, ‘Dendrobium Area 38 - Application for Approval to Extract Longwalls 14-18’, 02016/32556, Apr. 2016.

[5] P. Turner, ‘Some Concerns Regarding Groundwater Impact Assessments for Coal Mines in NSW’, NSW National Parks Association, Dec. 2016. [Online]. Available: https://drive.google.com/file/d/1vz1oeaat3-pfUyJ1hIL79cQmM-uKN7Pp/view?usp=sharing.

[6] P. Tammetta, ‘Preliminary Assessment of Methods for Estimating Streamflow Losses in the Special Areas’, Prepared for WaterNSW WNS001, Nov. 2018.

[7] Wollongong Coal Limited, ‘Wongawilli Colliery Nebo Area Project Approval (MP 09_161): Annual Review/Annual Environmental Management Report (1 July 2018 – 30 June 2019)’, Nov. 2019.

[8] G. McNally and R. Evans, ‘Impacts of longwall mining on surface water and groundwater, Southern Coalfield NSW’, Sinclair Knight Merz Pty Ltd, Report prepared for NSW Department of Environment and Climate Change., Sep. 2007.

[9] NSW Chief Scientist and Engineer, ‘On measuring the cumulative impacts of activities which impact ground and surface water in the Sydney Water Catchment’. May 2014, [Online]. Available: http://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0007/44485/140530_SCA-Report-Final-Combined.pdf.

[10] W. Minchin, S. Brown, B. Rollins, A. Skorulis, and N. P. Merrick, ‘Dendrobium Mine – Plan for the Future: Coal for Steelmaking - Groundwater Assessment’, NPM Technical Pty Ltd trading as HydroSimulations, Prepared for Illawarra Coal and South32 HS2018/67, May 2019.

[11] J. Jankowski and P. Knights, ‘Surface water-groundwater interaction in the fractured sandstone aquifer impacted by mining-induced subsidence: 1. Hydrology and hydrogeology’, in *Biuletyn Pañstwowego Instytutu Geologicznego*, Jan. 2010, vol. 441, 2010 R, pp. 43–54.

[12] S. Scarff, W. McLean, S. Brown, and R. Leslie, ‘Surface water – groundwater interaction in a mining impacted catchment – Waratah Rivulet’, Parsons Brinckerhoff Australia Pty Ltd, Prepared for the Sydney Catchment Authority 2114787A PR_6612, Apr. 2013.

[13] C. J. Booth, ‘The effects of longwall coal mining on overlying aquifers’, in *Mine Water Hydrogeology and Geochemistry. Younger PL and Robins NS (eds.)*, Special Publications., vol. 198, The Geological Society of London, 2002, pp. 17–45.

[14] N. Shepherd, J. Bennett, J. Galvin, C. Mackie, and J. Tilleard, ‘Review of the Bulli Seam Operations Project’. NSW Planning Assessment Commission (PAC), Jul. 2010, [Online]. Available: http://majorprojects.planning.nsw.gov.au/index.pl ?action=view_job&job_id=2673.

[15] W. McLean and E. Reece, ‘Collaborative Research Project - Impacts of Longwall Mining on Groundwater and Surface Water Resources in the Waratah Rivulet’, Parsons Brinckerhoff Australia Pty Limited, Parsons Brinckerhoff report prepared for the Sydney Catchment Authority, Jun. 2010.

[16] P. Tammetta, ‘Groundwater Study Area 3B Dendrobium Coal Mine - Numerical Modelling’, Coffey Geotechnics Pty Ltd, Groundwater assessment prepared for BHP Billiton GEOTLCOV24507AA-AB2, Oct. 2012. [Online]. Available: (http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=2010).

[17] P. Tammetta, ‘Groundwater Study, Area 3B Dendrobium Coal Mine, Data Analysis’, Coffey Geotechnics Pty Ltd, Groundwater assessment prepared for BHP Billiton GEOTLCOV24507AA-AB1, Oct. 2012.

[18] P. Tammetta, ‘Groundwater Study Area 3B Dendrobium Coal Mine Revised Numerical Modelling.’, Coffey Geotechnics Pty Ltd, Groundwater assessment prepared for BHP Billiton GEOTLCOV24507AB-AB2, Nov. 2012.

[19] P. Tammetta, ‘Groundwater Study, Area 3B Dendrobium Coal Mine, Data Analysis (2nd Edition)’, Coffey Geotechnics Pty Ltd, Prepared for BHP Billiton GEOTLCOV24507AB-AB1, Nov. 2012.

[20] P. Turner, ‘Concerns arising from flawed groundwater impact assessments in NSW’, NSW National Parks Association, Letter to NSW Minister for Planning, Jul. 2015.

[21] P. Hannam, ‘BHP’s coal mine approved in Sydney’s catchment without groundwater assessment’, *Sydney Morning Herald*, Jul. 31, 2015.

[22] S. Brown and W. Minchin, ‘Dendrobium Mine End of Panel Groundwater Assessment for Longwall 14 (Area 3B)’, HGEO Pty Ltd, Report prepared for South 32 Illawarra Coal D19326, Jun. 2019.

[23] GeoTerra Pty Ltd, ‘Wongawilli Colliery Nebo Longwall Panels 1 To 6 Groundwater Assessment’, GUJ4-GWR1B, Jun. 2010.

[24] K. Mills, ‘Update to Subsidence Assessment of Wollongong Coal Preferred Project Report Russell Vale No 1 Colliery - Appendix B of the Underground Expansion Project Residual Matters Report’, Strata Control Technology (SCT) Pty, WCRV4263, Jun. 2014.

[25] Metropolitan Coal, ‘Metropolitan Coal Longwalls 305-307 Water Management Plan’, Peabody, ME-TSE-MNP-0078 WMP-R01-B, Feb. 2020.

[26] P. Turner, ‘Some comments on the proposed extraction plan for Longwalls 305 to 307 at the Metropolitan Colliery and related matters’, National Parks Association of NSW, Mar. 2020.

[27] K. W. Mills and B. G. Blacka, ‘Experience of Monitoring the Interaction between Ground Deformations and Groundwater above an Extracted Longwall Panel’, in *Proceedings of the 10th Triennial Conference on Mine Subsidence*, Kirkton Park, Pokolbin, NSW, Nov. 2017.

[28] P. Tammetta, ‘Russell Vale Colliery (formerly the NRE No. 1 Mine) Underground Expansion Project Groundwater Review; Appendix A - Clarification’, Coffey Geotechnics Pty Ltd for the NSW Department of Planning, GEOTLCOV24840AC-AB, Sep. 2014.

[29] W. Ziegler and H. Middleton, ‘Is there a 4th Dimension to Subsidence Monitoring?’, in *Proceedings of the 9th Triennial Conference on Mine Subsidence*, May 2014, [Online]. Available: https://www.academia.edu/7083303/Is_there_a_forth_dimension_to_subsidence_monitoring.

[30] K. W. Mills, ‘Assessment of movement on shear planes between Avon Reservoir and the Dendrobium Area 3B mining domain to be conduits for increased flow.’, SCT Operations Pty Ltd, Prepared for Illawarra Coal and South32 DEN4936, Oct. 2018.

[31] T. Sullivan and G. Swarbrick, ‘Height of Cracking – Dendrobium area 3B’, Pells Sullivan and Meynink (PSM), Prepared for the NSW Department of Planning PSM3021-002R, Mar. 2017.

[32] K. Mills, ‘Assessment of Groundwater Data for Russell Vale Colliery and Implications for Further Mining in the Wonga East Area’, Strata Control Technology (SCT) Pty, Appendix C of the Russell Vale Colliery Underground Expansion Project Preliminary Residual Matters Report and Appendix D of Environmental Assessment Russell Vale Colliery Commencement of Long Wall 6 WCRV4209, Mar. 2014.

[33] WaterNSW, ‘WaterNSW comments on lllawarra Coal’s application for first workings for Dendrobium Longwall 16 within the Avon Dam Notification Area’, Letter to Dams Safety Committee 020181115179, Oct. 2018.

[34] S. Brown, ‘Review of groundwater monitoring at WC21 – Update February 2018’, HGEO Pty Ltd, HGEO Pty Ltd for Illawarra Coal and South32 D17280, Feb. 2018.

[35] Metropolitan Coal, ‘Metropolitan Coal Six Monthly Report 1 January to 30 June 2019’, Peabody, MET-19-20 00995871-002.

[36] GeoTerra Pty Ltd, ‘Gujarat NRE Coking Coal Ltd Preliminary Works Surface Water & Groundwater Assessment Bellambi, NSW’, GUJ3-R1C, Sep. 2010.

[37] A. Dawkins, ‘Appin Area 7 Longwalls 705 to 710 Groundwater Assessment’, Geoterra Pty Ltd on behalf of BHP-Billiton Illawarra Coal Pty Ltd, BHP41-R1B, Jun. 2008.

[38] Independent Expert Panel for Mining in the Catchment (IEPMC), ‘Advice to Energy and Resource Assessments IEPMC 2019-04: Dendrobium Coal Mine Longwall 21 Subsidence Management Plan’, Dec. 2019.

[39] Water NSW, ‘Dendrobium Area 38- Response to Submissions on SMP application for Longwall 16’, 2018146566, May 2018.

[40] WaterNSW, ‘Submission to the Independent Expert Panel for Mining in the Catchment’, D2019/8641, Mar. 2019.

[41] N. Shepherd, J. Bennett, J. Galvin, C. Mackie, and J. Tilleard, ‘The Metropolitan Coal Project Review Report’. NSW Planning Assessment Commission (PAC), May 2009, [Online]. Available: http://majorprojects.planning.nsw.gov.au/index.pl?action=view_job&job_id=2672.

[42] NSW Department of Planning, ‘Mining Impacts at Dendrobium Coal Mine Area 3B’, Report to Government, Dec. 2015.

[43] G. Miskelly, ‘“Shocking” metallic sludge contaminating Sydney dams that supply drinking water’, *Australian Broadcasting Corporation*, Dec. 01, 2019.

[44] J. Jankowski and P. Knights, ‘Surface Water–Groundwater Interaction in the Fractured Sandstone Aquifer Impacted by Mining-Induced Subsidence; 2. Hydrogeochemistry’, in *Biuletyn Pañstwowego Instytutu Geologicznego*, Jan. 2010, vol. 441, 2010 R, pp. 43–54.

[45] ‘Impact of Longwall Mining on Water Resources in Waratah Rivulet- An Update’, Sydney Catchment Authority, Science presentation to SCA Executive, 2011.

[46] Michael Williams & Associates Pty Ltd, ‘Qualitative Risk Assessment of Longwall Coal Mining in the Southern Coalfield of NSW: Key outcomes of a workshop hosted by Sydney Catchment Authority’. Jul. 24, 2013.

[47] P. Turner, ‘Some Comments on the revised draft water management plan for Longwalls 23 to 27 at the Metropolitan Colliery’, Letter to Sam Haddad Director General NSW Department of Planning, Mar. 2014.

[48] P. Tammetta, ‘Gujarat NRE No.1 Colliery Major Expansion Project Part 3A Application: Review of the Groundwater Component of the Preferred Project Report - June 2013’, Coffey Geotechnics Pty Ltd for the NSW Department of Planning, GEOTLCOV24840AB-AB, Jun. 2013.

[49] WaterNSW, ‘Supplementary comments on Dendrobium Area 38-Application for SMP Approval to extract Longwall 16’, WaterNSW, 02018/11146, Feb. 2018.

[50] M. J. Currell, A. D. Werner, C. McGrath, J. A. Webb, and M. Berkman, ‘Problems with the application of hydrogeological science to regulation of Australian mining projects: Carmichael

Mine and Doongmabulla Springs', *J. Hydrol.*, vol. 548, pp. 674–682, May 2017, doi: 10.1016/j.jhydrol.2017.03.031.

[51] M. J. Currell and A. D. Werner, 'Unpacking the flaws in Adani's water management plan', *The Conversation*, May 2019.

[52] NSW Mining & Petroleum Gateway Panel, 'Report by the Mining & Petroleum Gateway Panel to accompany a Conditional Gateway Certificate for the Caroona Coal Project', NSW Mining & Petroleum Gateway Panel, Jul. 2014.

[53] WaterNSW, 'Dendrobium Area 38 - Application for SMP Approval to extract Longwall 16', WaterNSW, D2017/144759, Dec. 2017.

[54] Independent Expert Panel for Mining in the Catchment (IEPMC), 'Independent Expert Panel for Mining in the Catchment Report: Part 1 Review of specific mining activities at the Metropolitan and Dendrobium coal mines', Office of the Chief Scientist & Engineer, Oct. 2019.

[55] J. Galvin, 'Review of PSM Report on Height of Fracturing – Dendrobium Area 3B', Galvin & Associates, Prepared for NSW Department of Planning, Feb. 2017.

[56] C. Mackie, 'Height of fracturing at Dendrobium Mine – Peer review of PSM report', Mackie Environmental Research Pty. Ltd, Prepared for NSW Department of Planning 906/17, Feb. 2017.

[57] P. Turner, 'Some Comments on the 2017 PSM, Galvin and Mackie height of cracking reports for the Dendrobium coal mine', National Parks Association of NSW, Jul. 2018. [Online]. Available: https://drive.google.com/open?id=1BiJQr37B2dPEivoiJn4pizl-vBWy4d9F.

[58] B. Medway, B. Keogh, B. Whitehill, and R. Lucas, '2016 Audit of the Sydney Drinking Water Catchment', Alluvium Consulting Australia, Jun. 2017.

[59] Commonwealth of Australia 2014, 'Temperate Highland Peat Swamps on Sandstone: longwall mining engineering design—subsidence prediction, buffer distances and mine design options, Knowledge Report', prepared by Coffey Geotechnics for the Department of the Environment, Commonwealth of Australia., Aug. 2014.

[60] M. Krogh, 'Assessment of Impacts over Dendrobium Mine'. NSW Office of Environment & Heritage, Aug. 31, 2012.

[61] B. K. Hebblewhite, J. Galvin, C. Mackie, R. West, and D. Collins, 'Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield - Strategic Review'. NSW Department of Planning, Jul. 2008, [Online]. Available: http://www.planning.nsw.gov.au/planningsystem/pdf/report_southern_coalfields_final_jul08.pdf.

[62] M. Krogh, 'Management of longwall coal mining impacts in Sydney's southern drinking water catchments', *Australas. J. Environ. Manag.*, vol. 14, no. 3, pp. 155–165, Sep. 2007.

[63] A. Bray, 'A tectonostratigraphic model for the Camden Syncline within the context of the greater Sydney Basin', PhD, University of Sydney, 2013.

[64] J. Jankowski, ‘Hydrological Responses and Monitoring Program Design in Longwall Mining Catchments, Southern Coalfield, New South Wales, Australia’, presented at the Groundwater in the Sydney Basin Symposium, Sydney NSW, Aug. 2009.

[65] G. Brassington and W. Tyrrell, ‘Independent Inquiry into NSW Southern Coalfield Illawarra Coal Submission’. Illawarra Coal Holdings Pty Ltd, BHP-Billiton, Jul. 30, 2007.

[66] Department of Environment and Climate Change, ‘Submission on the strategic review of the impacts of underground mining in the Southern Coalfield - Attachment 1 - DECC Scientific Services Report – Ecological Impacts of Longwall Mining in the Southern Coalfields of NSW – A Review’. NSW Government, Jul. 30, 2007.

[67] P. Tammetta, ‘Estimation of the height of complete groundwater drainage above mined longwall panels’, *Ground Water*, vol. 5, pp. 723–34, Oct. 2013, doi: 10.1111/gwat.12003.

[68] P. Tammetta, ‘Estimation of the Change in Hydraulic Conductivity Above Mined Longwall Panels. Supporting Information.’, *Groundwater*, vol. 53, no. 1, pp. 122–129, Jan. 2015, doi: 10.1111/gwat.12153.

[69] Mine Subsidence Engineering Consultants (MSEC), ‘Dendrobium Area 3B – Longwalls 12 to 18: Review of the Subsidence Predictions and Impact Assessments for Natural and Built Features in Dendrobium Area 3B based on Observed Movements and Impacts during Longwalls 9 and 10’, Mine Subsidence Engineering Consultants Pty Ltd (MSEC), MSEC792 Revision C, Dec. 2015.

[70] NSW Office of Environment and Heritage, ‘Upland Swamp Environmental Assessment Guidelines - Guidance for the underground mining industry operating in the southern coalfield’. NSW Government, Aug. 2012.

[71] Mine Subsidence Engineering Consultants (MSEC), ‘Dendrobium Area 3B – Longwalls 9 to 18 Subsidence Predictions and Impact Assessments for Natural Features and Surface Infrastructure in Support of the SMP Application’, Mine Subsidence Engineering Consultants Pty Ltd (MSEC), MSEC459 Revision B, Sep. 2012.

[72] B. K. Hebblewhite, F. Kalf, and T. McMahon, ‘Woronora Reservoir Strategy Report – Stage 1: Metropolitan Coal Longwall mining near and beneath Woronora Reservoir’, Sep. 2017.

[73] Sydney Catchment Authority, ‘Longwall Mining - Presentation to SCA Board’, 2011.

[74] B. K. Hebblewhite, F. Kalf, and T. McMahon, ‘Woronora Reservoir Strategy Report – Stage 2: Metropolitan Coal Longwall mining near and beneath Woronora Reservoir’, Jun. 2019.

[75] Department of Environment, Climate Change and Water NSW, ‘2010 Audit of the Sydney Drinking Water Catchment’, NSW Government, DECCW 2010/973, Nov. 2010.

Figures

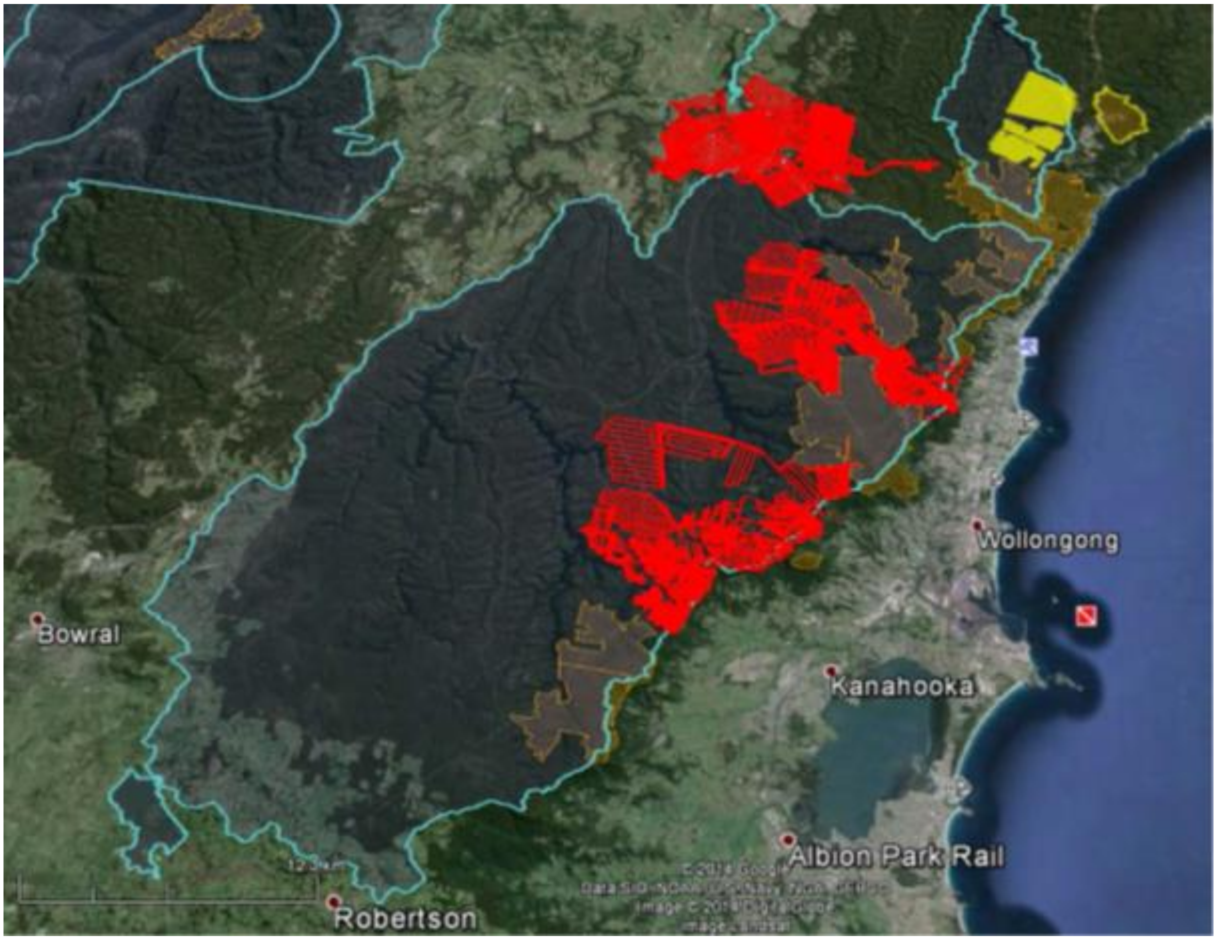


Figure 1. Google Earth depiction of coal extractions (with current approvals) within and adjacent to the Metropolitan and Woronora Schedule 1 Special Areas.

The Special Areas are depicted with pale-blue boundaries. The Metropolitan Special Area is centred in the image while the Woronora Special Area is the smaller region in the top right of the image. Part of the Schedule 1 Warragamba Special Area is shown at the top left. The red and yellow areas represent longwall mines, while the ‘amorphous’ shaded regions, represent older bord and pillar mine areas. The extent of pillar removal from the bord and pillar mine areas is uncertain.

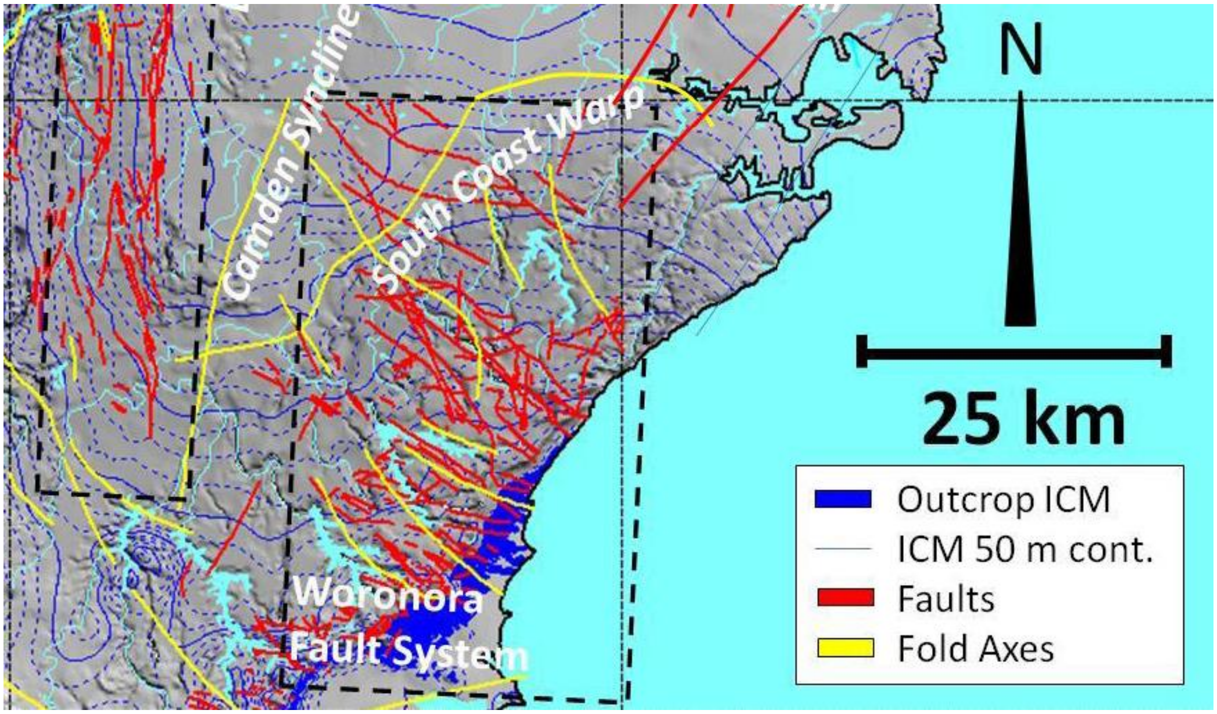


Figure 2. Depiction of faults and folds in the Illawarra region of the Sydney Basin**[63]**, showing a concentration of faults between the storage reservoirs.

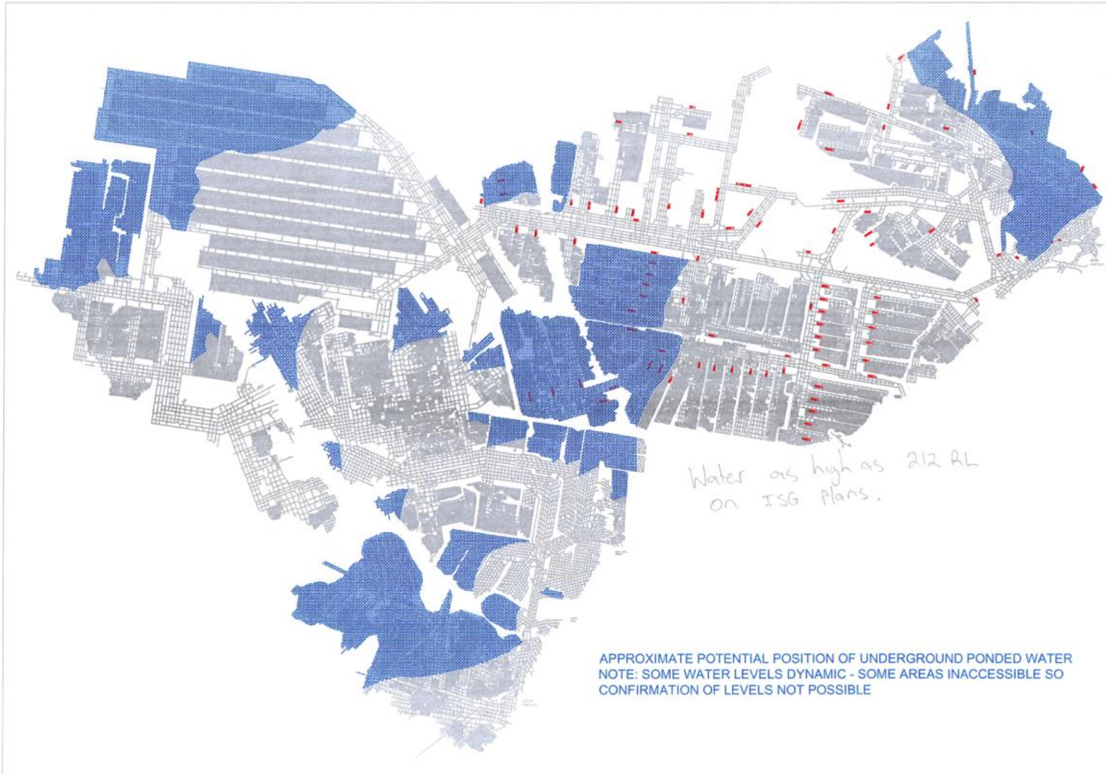


Figure 3. Water lodgement in Wongawilli coal seam extraction areas at the Wongawilli mine.

Provided on request by Wollongong Coal, the date of the above water lodgement map is not known. The printed text states: "A*pproximate potential position of underground ponded water. Note: some water levels dynamic - some areas inaccessible so confirmation of levels not possible*". The handwritten note states "*Water as high as 212 RL on ISG plans*"; it's not known which part of the mine is referred to in this comment. Wollongong coal had been extracting remnant in the Nebo section when operations ceased in 2019 because of safety concerns. The area has been sealed and the Community Consultative Committee has been told that its anticipated that when the ponding reaches about 205 RL, water will drain from a portal in the escarpment, near Dombarton.

The Bulli seam above has also been mined and may hold water. Ponding and draining is known to be occurring at the other mines in and around the Special Areas.

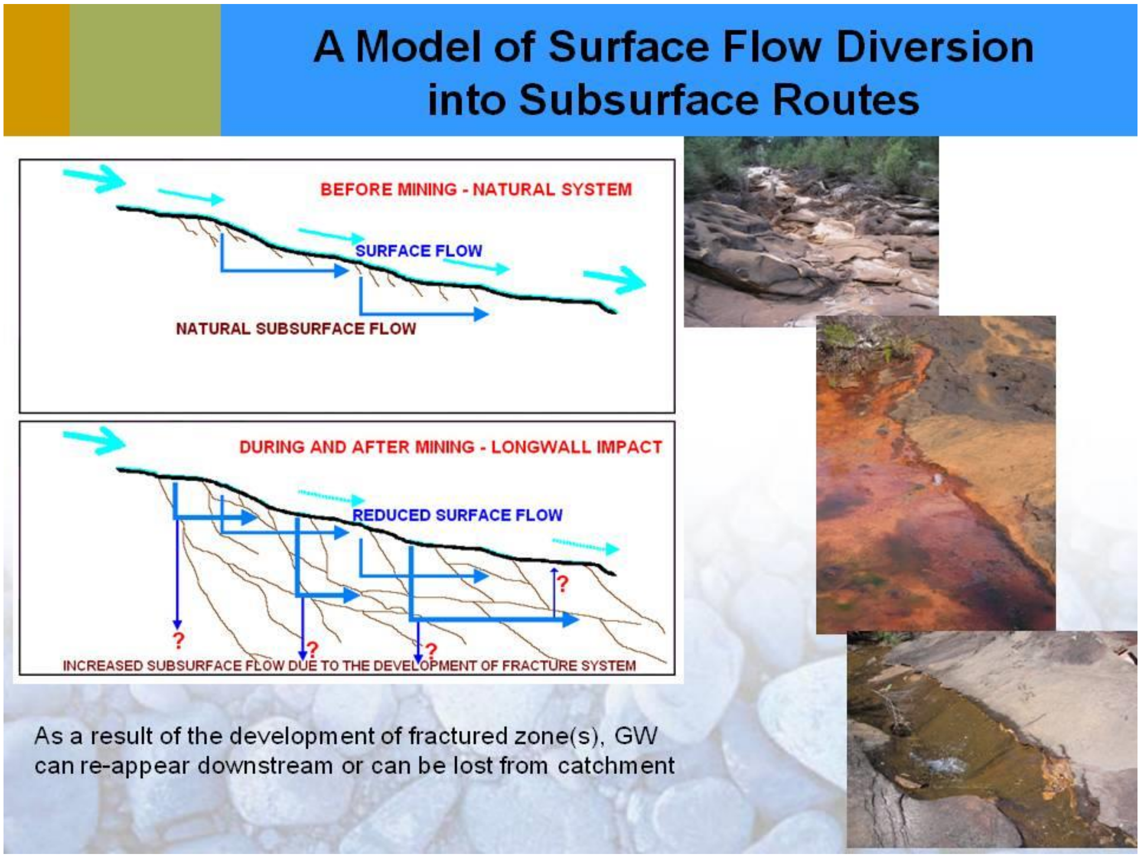


Figure 4. Sydney Catchment Authority (now WaterNSW) depiction**[64]** of surface water diversion and fracture network water flow.

Figure 5. Damage and drainage on Wongawilli Creek resulting from subsidence at Elouera Colliery.[65], [66]

Adjoining the Dendrobium mine, the Elouera Colliery is now part of the Wongawilli mine.

The 2010 groundwater impact assessment for the 2010 longwall mining proposal for the Nebo area of the Wongawilli mine reports:

> "*bord and pillar as well as pillar extraction and longwall mining has been conducted in the adjacent Wongawilli, Elouera and Dendrobium Area 2 workings, and that vertical hydraulic connection has been observed at some locations between surface streams and the underlying workings*".[23]

The assessment report further comments that a significant but unquantified component of the water entering the Elouera mine comes "*from surface water seeping through subsidence cracks following extraction of Elouera Longwalls 6 and 7 under Wongawilli Creek*"

(a)

(b)

Figure 6. Watercourse damage examples

(a) Water draining in low-flow conditions into a crack in the floor of Waratah Rivulet. Damage of this kind has occurred over and around all of the mining in the Metropolitan and Woronora Special Areas. Of note, Waratah Rivulet provides more water to Woronora Reservoir than does Woronora River. **(b)** Watercourse cracking over a drainage zone that reaches the surface is likely to be the reason sections of Wongawilli Creek tributary WC21, over the Dendrobium mine, have been drained. Such impacts have also drained swamps over the Dendrobium mine.

(a) **(b)**

Figure 7. (a) Fragment of polyurethane resin (PUR) from Waratah Rivulet (b) Aging PUR curtain in Waratah Rivulet bedrock.

The effectiveness of a polyurethane resin (PUR) barrier may be limited, particularly during low flow periods. The ability of the quite brittle material to resist further subsidence movements would seem likely to be limited and its medium to long term durability is also questionable. The watercourse functionality and groundwater impact of injected flow barriers has not been adequately studied.

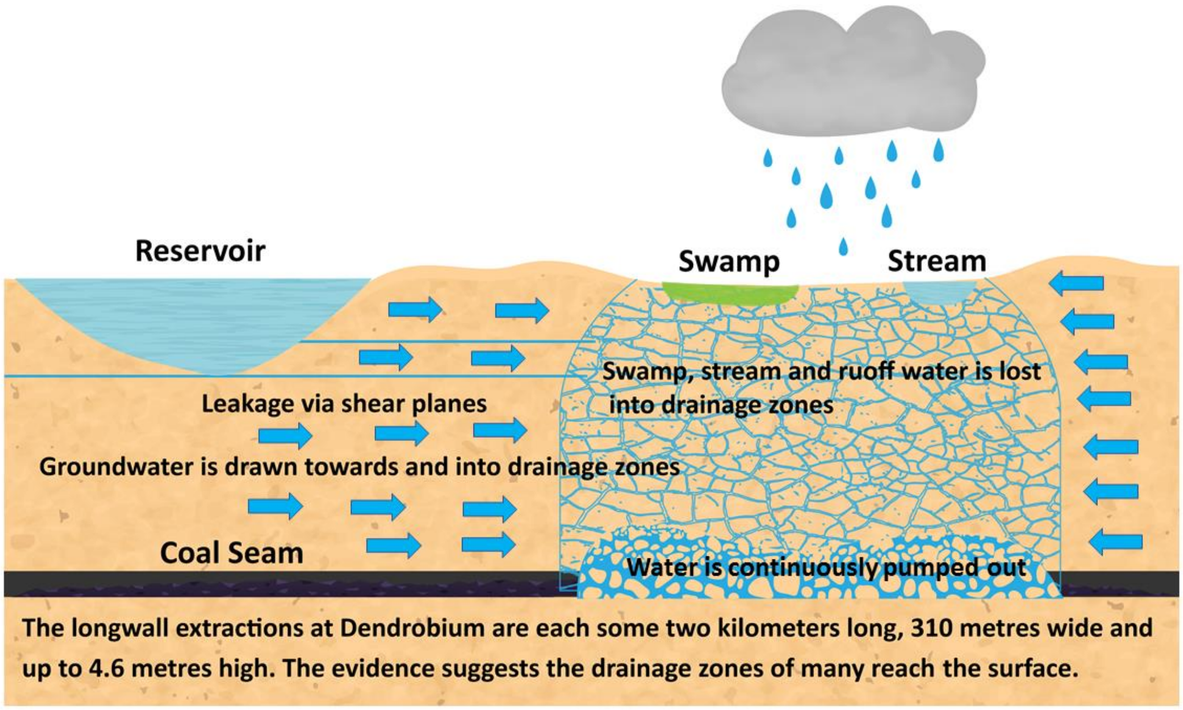


Figure 8. Depiction of the drainage zone reaching the surface beneath a swamp and watercourse, and near a reservoir.

The drainage zone, or zone of complete drainage, is a zone of highly connected fractures that forms over a coal extraction. Surface and groundwater is drawn into this zone, where it then drains relatively rapidly to the mine. The height of the drainage zone depends primarily on the extraction width, height (thickness) and depth below the surface.[67] The mining parameters at the Dendrobium mine are such that the drainage zone may reach the surface over parts the mine. At least in part reflecting this outcome, the inflow of water to the mine is rainfall dependent and has reached peaks of up to 13 million litres a day.

Like reservoirs, watercourses not over a drainage zone may lose water via shear planes.

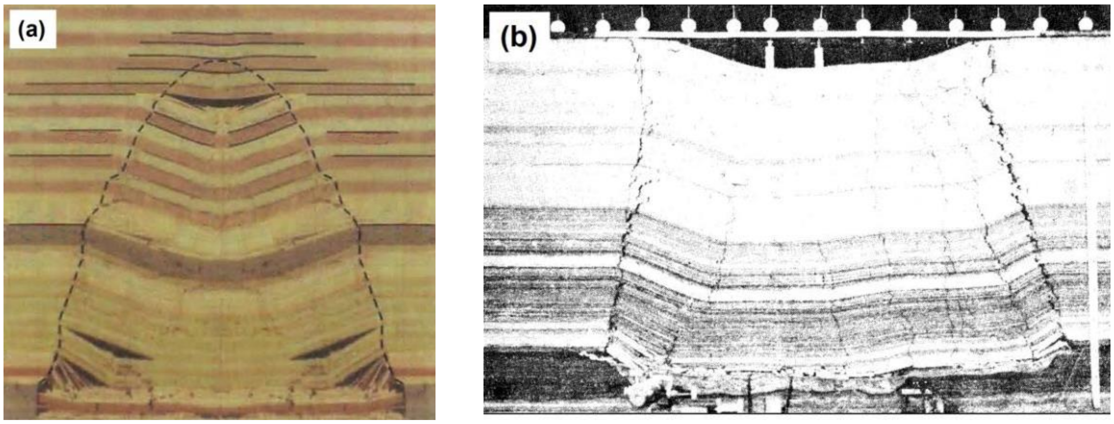
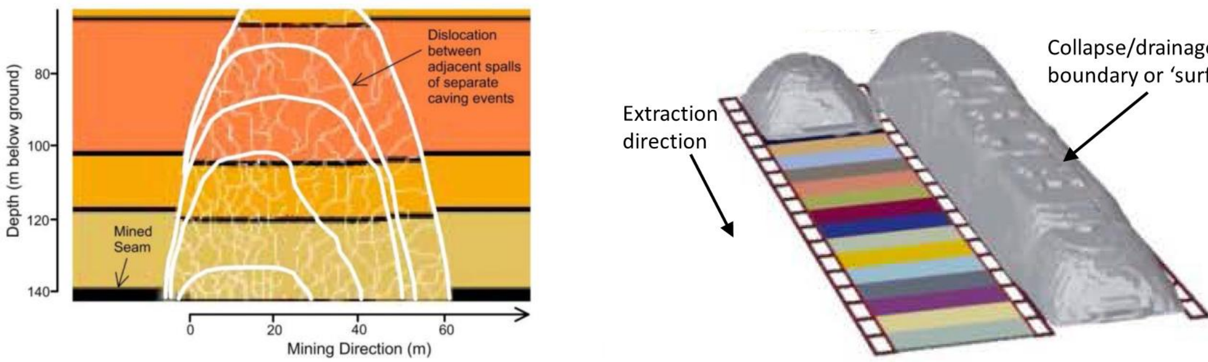


Figure 9. Physical models of the collapsed zone over a coal extraction

(a) Physical model of the collapse of strata downwards and into the void created by coal extraction.[68] Evidence and calculations suggest that the drainage zone formed with this collapse reaches the surface over parts of the Dendrobium mine. It may also have occurred where pillar extraction has taken place. **(b)** Physical model of the complete collapse that occurs when the extraction width has passed the point beyond which the rock strata above the extraction is unable to 'bridge' the extraction void.[68] Known as ‘supercritical’, this is thought to have occurred over some of the coal extractions at Dendrobium. While further extraction beyond the critical width doesn’t result in any further surface subsidence, the lateral extent of mine to surface fracturing continues to increase.



(a) **(b)**

Figure 10. Evolution of the drainage zone

(a) Evolution of the collapse zone in the early stages of a longwall extraction, based on data from a Queensland mine.[68] Also known as the zone of complete drainage or drainage zone, this is a zone of connected fractures where water drains relatively rapidly towards the void created by a coal extraction. Evidence and estimates of the height of the drainage zone suggest it has reached the surface over parts of the Dendrobium mine. **(b)** Three dimensional simulation[68] of the boundary of the collapse/drainage zone over a completed longwall extraction and over the early stage of a second extraction, in which the rock surrounding the drainage zone boundary is not shown.

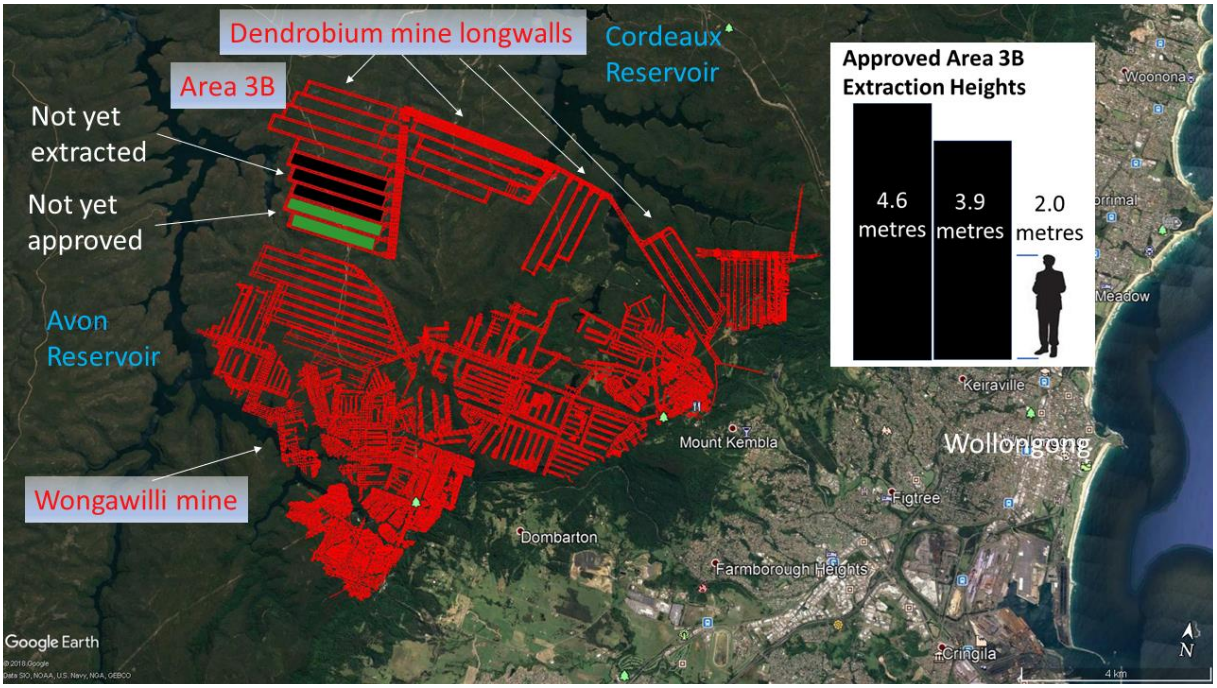


Figure 11. Extent of underground coal mining between the Avon and Cordeaux Reservoirs.

Since this graphic was created, Longwall 14 has been completed and Longwall 17 has been approved. With approved longwall extractions in Area 1, 2, 3A, 3B and 3C, the Dendrobium coal mine is located between the Avon and Cordeaux Reservoirs. The Department of Planning approved extraction dimensions in Area 3B are unusually large with each longwall 'panel' having a width of 305 metres and a height (or thickness) of between 3.9 and 4.6 metres. The first extraction in Area 3C, Longwall 21, was recently approved by the Department of Planning with dimensions that may result in the drainage zone joining the surface fracture network, if not reaching the surface.

extraction height at Wongawilli is also less than at the Dendrobium mine. The Nebo area was closed in 2019 for safety reasons.

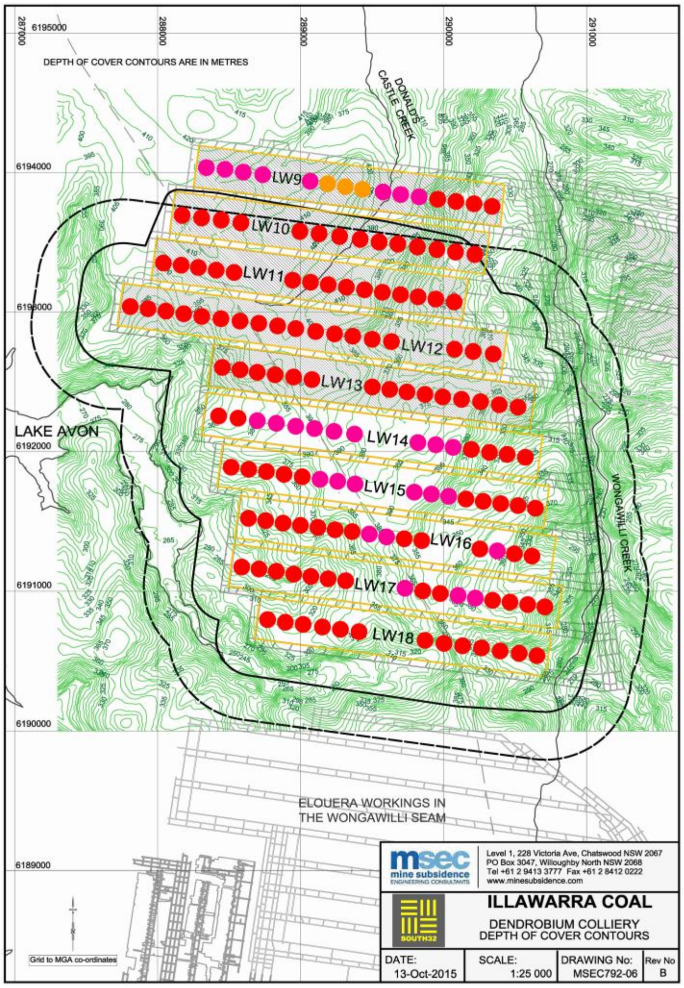


Figure 12. Depiction of estimated drainage zones peaks with respect to the surface above Dendrobium Area 3B.

This augmented MSEC map[69] shows the layout of the longwalls of Area 3B of the Dendrobium mine, together with depth of cover contours. Longwalls 9 to 13 were approved in February 2013, 14 and 15 were approved in December 2016, 16 was approved in May 2018 and 17 in July 2019. The shaded longwalls are those that had been extracted at the time the map created. Longwall 14 commenced in May 2018 and was completed in February 2019. Longwall 15 is being extracted at the time of writing. Coloured circles have been added to the MSEC map to indicate the Tammetta equation[67] estimates of the height of the drainage zone that will form above the 3.9 high extractions (LWs 9 and 14 to 18) and 4.6 metre high extractions (LWs 10 to 13) approved to date by the Department of Planning. A pink indicates that the drainage zone at that point reached between 25 metres from the surface and the surface, while red indicates intersection with the surface. Reducing the extraction height from 4.6 metres to 3.9 metres (see Fig. 11) does not significantly reduce the impact of the mining.

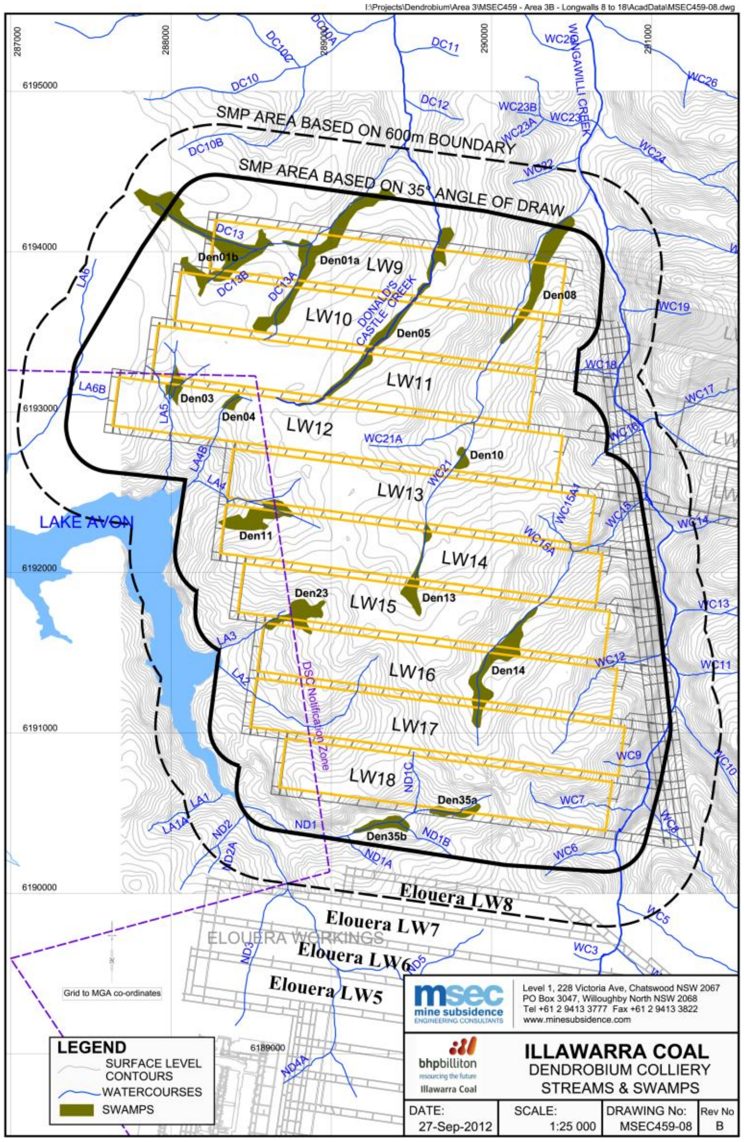


Figure 13. The swamps and watercourses over Area 3B of the Dendrobium mine

Swamps 1a, 1b, 5 and 8 extend over Longwalls 9, 10 and 11 of the Dendrobium mine and are amongst the largest and most complex swamps on the Woronora Plateau. They would merit recognition as being of special significance.[70] They were the first to be impacted by the mining in Area 3B of the Dendrobium mine. Numbers for the longwalls in the Elouera domain of the adjoining Wongawilli mine have been added to this 2012 MSEC map of then planned mining for Area 3B.[71]

Figure 14. Map of mining below and near Cataract Reservoir.**[72]**

Mining took place beneath the reservoir between 1993 and 2000. A 2014 paper[29] by the Dams Safety Committee reports evidence of shear plane leakage and the study also found that subsidence movements continued, with reactivation, for 25 years after completion of the mining; much longer than found elsewhere in the Special Areas.

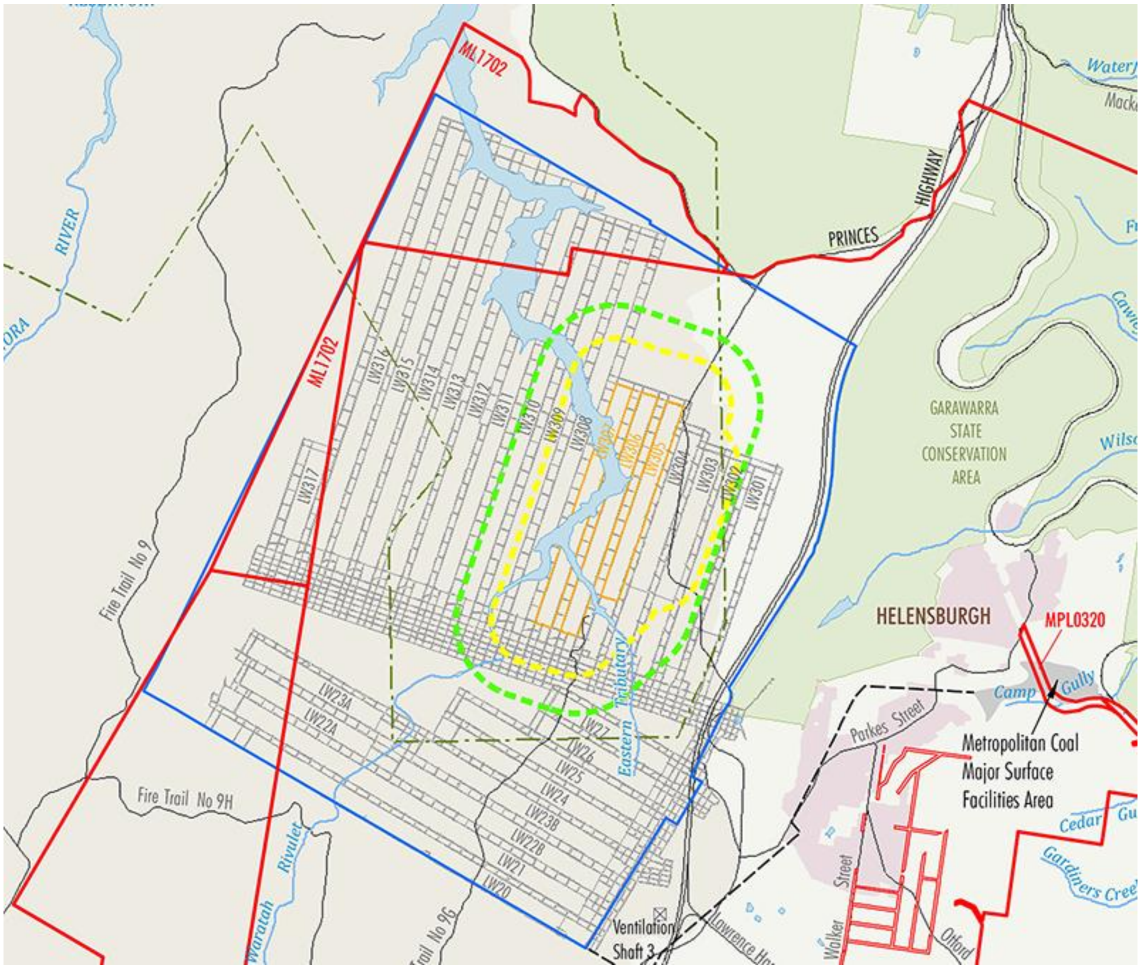


Figure 15. Map of mining below Woronora Reservoir.**[25]**

Longwalls 305 to 307, the first longwalls to pass below Woronora Reservoir, are highlighted. These extractions were approved by the Department of Planning in March 2020.

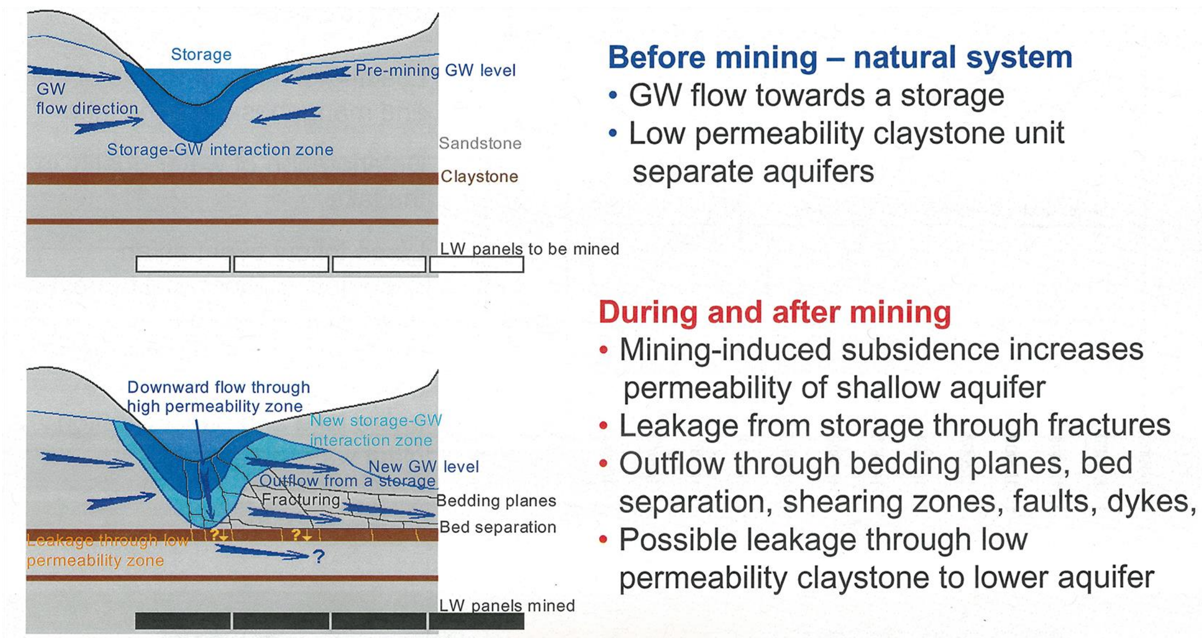


Figure 16. Sydney Catchment Authority (now WaterNSW) depiction of risks of mining below a reservoir

The above depiction[73] doesn't explicitly include shear plane activation. Leakage through these impacts would not result in water entering the mine. Data, knowledge and modelling limitations are such that currently it is not possible to reliably estimate losses of this kind. In particular it is not possible to establish a sufficiently accurate and precise reservoir water balance model (see Fig. 17).

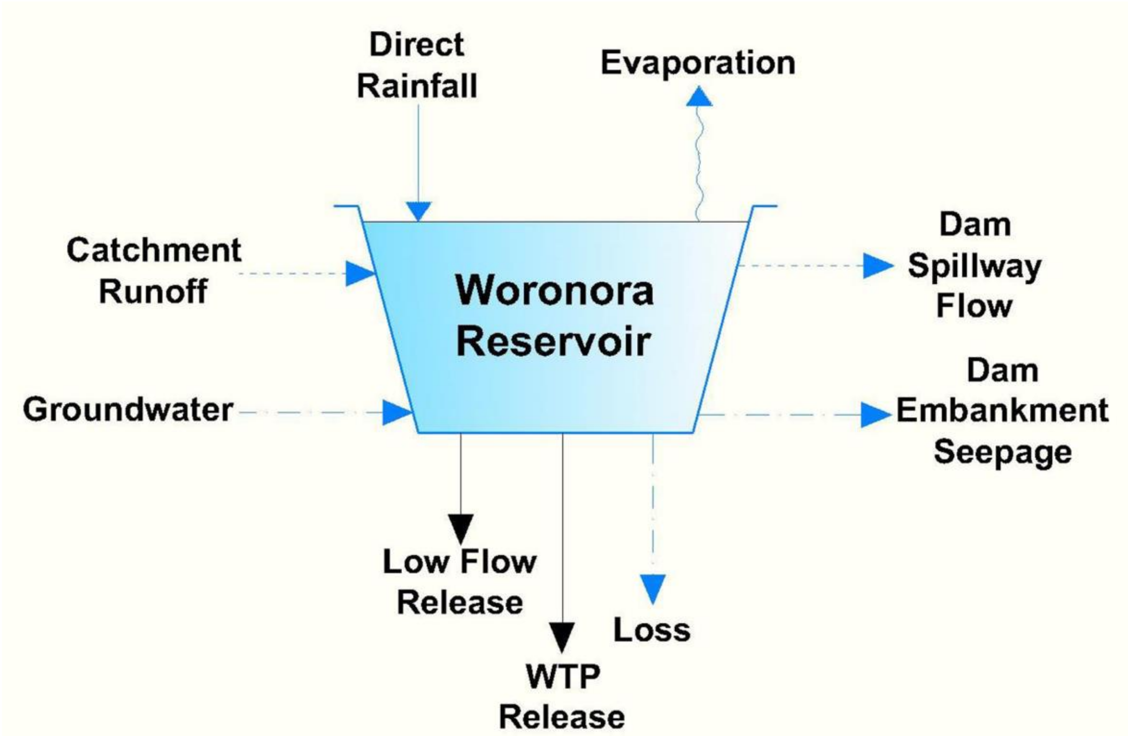


Figure 17. Water balance depiction for Woronora Reservoir.**[74]**

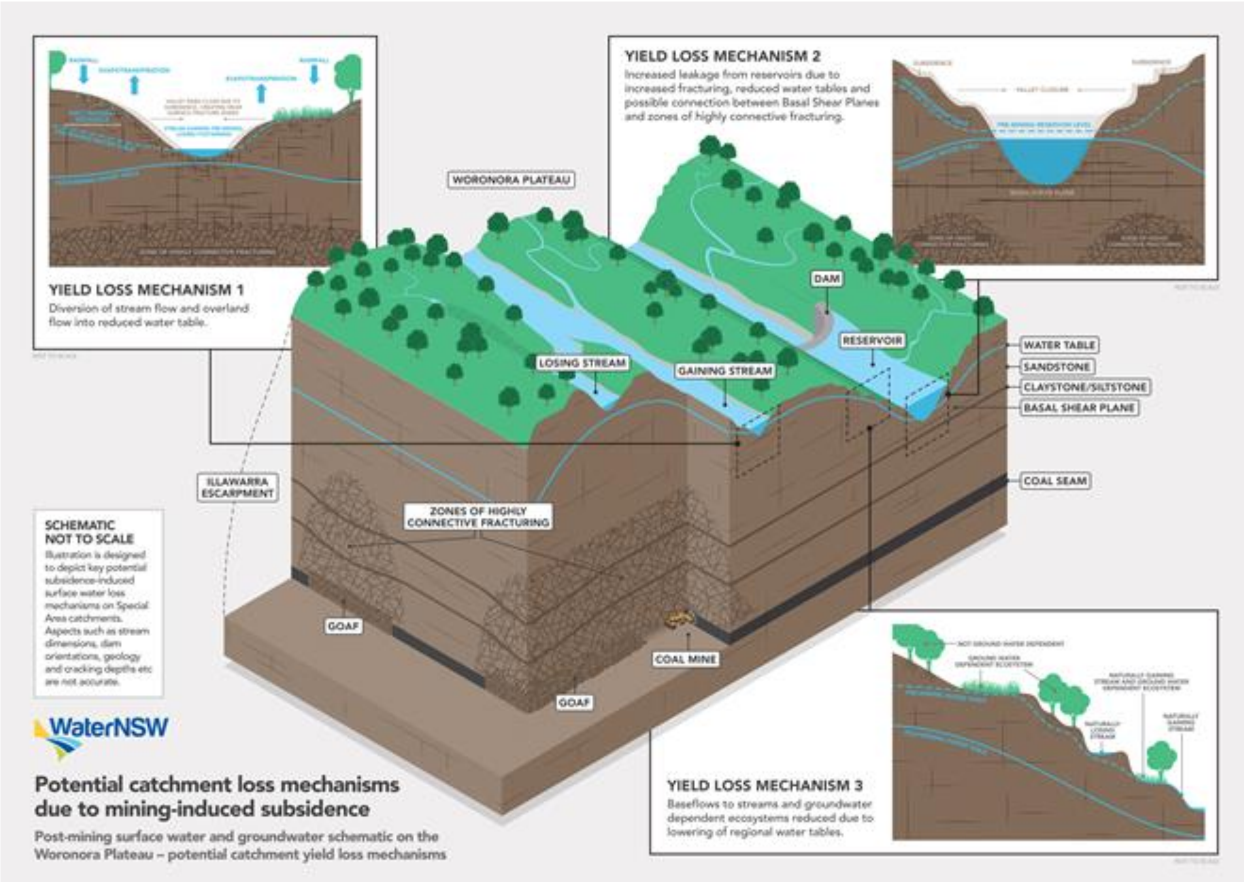


Figure 18. WaterNSW depiction of mechanisms by which water is lost from the catchment.

(a) Mechanism 1: Diversion of stream flow and runoff into fracture networks that join groundwater inflows to the mine or join groundwater flows that take water away from the local catchment. **(b) Mechanism 2**: reservoir leakage into mining induced fractures formed through processes such as ‘valley bulging’, leakage into ‘shear’ planes connected to fracture networks, and groundwater ‘base flow’ decline and loss. **(c) Mechanism 3**: Groundwater decline resulting in a loss of runoff and groundwater base flow to streams, such that they change from being ‘gaining’ to ‘losing’ watercourses.

These impacts are found above all of the mining in the Illawarra Special Areas; the amount of water being lost from the storage areas is not reliably known.

The depiction is for comparatively modest mining and, accordingly, the highly connected fracture zone, the drainage zone,

(a)

(b)

Figure 19. Iron spring degradation of Waratah Rivulet

(a) Iron spring discharge via a subsidence crack into Pool H on Waratah Rivulet. **(b)** Iron staining a short distance downstream from Pool H. Iron springs are formed when water passing through fresh rock fractures dissolves minerals from the rock. Iron springs are common over the mines and, reflecting this, the location of the mines can be determined from the air[46], when flying over the Special Areas. Groundwater inflows to reservoirs are similarly contaminated by mining impacts.

Figure 20. Mine water discharge damage to Lizard Creek Swamp

A 2010 Sydney Catchment Authority (now WaterNSW) photograph[75] of a 2004 discharge of alkaline mine water from Russell Vale Colliery onto Lizard Creek Swamp in the Metropolitan Special Area. A visit in 2013 found limited partial recovery.

As the IEPMC points out, discharges of this kind will occur above mines that have caused mine to surface connected cracking, if pumping stops and the mine is closed and sealed. Connected mine to surface cracking has occurred at the Dendrobium mine and the adjoining Wongawilli mine.

(a)

(b)

Figure 21. Swamp loss at the Dendrobium mine

(a) Dehydrating vegetation in Swamp 1b over Area 3B of the Dendrobium mine in early September 2016. Even though there had been significant rainfall in the previous three months, there was no water discharge from the swamp and the stream it would otherwise supply was dry. **(b)** The swamp sediment was firm and dry, whereas it should be soft, wet and dark brown or black in colour with decayed organic matter. In this condition the sediment would readily burn in the event of a fire. There was some sediment moisture in the centre of the swamp.

Curriculum vitae

Ian Alexander Wright

Email: i.wright@westernsydney.edu.au

Current Position: Western Sydney University: Senior Lecturer

Key knowledge / skills / experience

I am an environmental scientist, manager, lecturer and researcher. I have worked as an environmental scientist with industry for more than 25 years. I am an advocate for sustainable water and catchment management and I strongly support multi-disciplinary projects. I seek to manage industry problems with evidence-based science. I have specialist scientific expertise in freshwater ecology, water chemistry, pollution ecology of waters, freshwater macroinvertebrates as pollution indicators, impact of urban development, sewage effluent, agricultural, and mine waste impacts on streams and rivers. I have expertise in the sampling design of environmental science studies and statistical analysis of environmental data. I have published 76 peer-reviewed publications. I have provided independent expert testimonies for environmental science matters for the NSW Land & Environment Court. I am also an enthusiastic participant in community engagement activities in my field of expertise.

Education

- **Doctor of Philosophy (2006)** University of Western Sydney. Thesis title *'Midges (Chironomidae: Diptera) in Australian freshwater lakes and upland streams'*.
- **Master of Science (by research) (1994)**, Graduate School of the Environment, Macquarie University. Thesis title *'Ecological impact of the Wentworth Falls Sewage Treatment Plant on Blue Mountain Creek'*.

  Bachelor of Applied Science (Agriculture) with Merit (1988), Hawkesbury Agricultural College (now part of University of Western Sydney).

Employment History – academic

<u>School of Science, Western Sydney University (WSU).</u>

I have been employed by WSU as a lecturer since 2010:

- **February 2010 – July 2012 - Casual Lecturer**
- **July 2012 to December 2013 - Teaching focussed Associate Lecturer (18 month term)**
- **January 2014 to December 2016 - Lecturer**
- **January 2017 – present Senior Lecturer**

Research

Research Highlights

- Winner of the 'Research Impact' competition for School of Science and Health (15 July 2016) and won the Western Sydney University final (both overall and also audience choice prizes) on 25 October 2016.
- Part of WSU 2018 ARC submission – team research was considered 'high impact'
- My research has contributed to improved scientific knowledge as well as advances in the regulation and management of water pollution from Sydney basin coal mines.
- Member of three NSW EPA / Industry stakeholder groups that are contributing to revised and improved regulations to reduce water pollution from three Sydney basin coal mines.
- Have published more peer-reviewed research papers on the topic of Australian coal mine water pollution than any other academic over the last 25 years.
- Engaged by the Commonwealth Government to conduct an independent investigation of impacts from a coal mine sediment spill on the world heritage values of the Wollangambe River.
- Engaged as water expert to conduct independent audit of water quality and river health in Sydney's drinking water catchment rivers and storages in 2016/ 17 . The audit reports are public and were tabled in NSW Parliament in August 2017.
- Engaged as water science expert to contribute to Commonwealth Government funded 'City Deal' 'Engineering Design Manual' for Western Sydney Councils.
- Have provided independent expert witness advice in four major industrial/coal mine / urban water pollution court cases.
- Published 44 peer-reviewed journal articles (C1) over my career.
- Published 32 peer-reviewed conference papers (E1) over my career.
- Delivered numerous keynote and other presentations to industry and community.
- Received extensive media coverage on my research and my knowledge and experience in the water industry (across digital, print, radio and TV).
- Have received regular requests from politicians, community and industry to provide expert advice on a spectrum of water issues relating to my research expertise.

Peer-reviewed journal publications

1. Katie Purdy, Jason K Reynolds and **Wright IA** (2020) Potential water pollution from recycled concrete aggregate material '*Marine and Freshwater Research'* (2020-3) J44
2. Caroll R, Reynolds JK, **IA Wright** (2020) Geochemical signature of urbanisation in Blue Mountains Upland Swamps. *Science of the Total Environment*. (2020-2) J43
3. Belmer and **Wright IA** (2020) The regulation and impact of eight Australian coal mine waste-water discharges on downstream river water quality: a regional comparison of active versus closed mines *Water and Environment Journal* `(2020-1) (J42)
4. N Belmer, K Paciuszkiewicz, **IA Wright** (2019) Regulated Coal Mine Wastewater Contaminants Accumulating in an Aquatic Predatory Beetle (Macrogyrus rivularis): Wollangambe River, Blue Mountains New South Wales Australia. *American Journal of Water Science and Engineering* 5 (2), 76-87 (2019-5) J41

5. N Belmer, **IA Wright** (2019) Regional Comparison of Impacts to Stream Macroinvertebrates from Active and Inactive Coal Mine Wastewater Discharges, Sydney Basin, New South Wales Australia. *American Journal of Water Science and Engineering* 5 (2), 62-75 (2019-4) J40

6. Belmer N, **Wright IA** (2019). Regional Comparison of Impacts from Seven Australian Coal Mine Wastewater Discharges on Downstream River Sediment Chemistry, Sydney Basin, New south Wales Australia. *American Journal of Water Science and Engineering*.Vol. 5, No. 2, 2019, pp. 37-46. doi: 10.11648/j.ajwse.20190502.11 (2019-3) J39

7. Paciuszkiewicz, Ryan, **Wright IA** and Reynolds (2019) Variations in illicit compound discharged from treated wastewater. *Water* (2019-2) J38

8. Morrison KG, Reynolds JK and **Wright IA** (2019) Subsidence fracturing of stream channel from longwall coal mining causing upwelling saline groundwater and metal-enriched contamination of surface waterway *Water Air Soil Pollution* (2019-1) (J37)

9. Tippler C, **Wright IA** and Davies P (2018) Are Odonata nymph adversely affected by impaired water quality in urban streams *Austral Ecology* (J36)

10. Belmer N, **Wright IA**, Tippler, C (2018) Aquatic ecosystem degradation of high conservation value upland swamps, Blue Mountains Australia. *Water, Air, & Soil Pollution*.

11. Vince Geiger, Joanne Mulligan, Liz Date-Huxtable, Rehez Ahlip, D. Heath Jones, E. Julian May, Leanne Rylands, **IA Wright** (2018) An interdisciplinary approach to designing online learning: Fostering pre-service mathematics teachers' capabilities in mathematical modelling to appear in **ZDM Mathematics Education**

12. Grella C, Renshaw A, **Wright IA** (2018) Invasive weeds in urban riparian zones: the influence of catchment imperviousness and soil chemistry across an urbanization gradient. *Urban Ecosystems* DOI: 10.1007/s11252-018-0736

13. **Wright IA,** Belmer, N (2018) Increased water pollution after closure of Australia's longest operating underground coal mine: A 13-month study of mine drainage, water chemistry and river ecology. *Water, Air, & Soil Pollution*.
14. Ali A., Vladimir Strezov, Peter Davies, **IA Wright**, (2018) River sediment quality assessment using sediment quality indices for the Sydney basin, Australia affected by coal and coal seam gas mining *Science of the Total Environment*
15. **Wright IA,** Khoury, R., Ryan, M., Belmer, N., and J.K. Reynolds (2018) Impact of concrete of different fragment sizes on urban water chemistry: a case study using water from a high conservation-value waterway. *Urban Water Journal*
16. Ali, A. & V. Strezov & P. Davies & **I. Wright** (2017) Environmental impact of coal mining and coal seam gas production on surface water quality in the Sydney basin, Australia. *Environ Monit Assess.*
17. Ali A, Strezov V, Davies P, **Wright I,** Kan T, (2017), Impact of coal mining on river sediment quality in the Sydney basin, Australia, *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering*, vol 11, no 4, pp 243-248, [REDI ID: 245753]
18. **Wright I,** Belmer N, Davies P, (2017), Coal mine water pollution and ecological impairment of one of Australia's most 'protected' high conservation-value rivers, *Water, Air, and Soil Pollution*, vol 228, no 3, [REDI ID: 245410]

19. Price P, **Wright, I.A.** (2016) Water quality impact from the discharge of coal mine wastes to receiving streams: comparison of impacts from an active mine with a closed mine, submitted to *Water, Air, and Soil Pollution*, vol 226, no 10, [ORS ID: 239437]
20. **Wright, I.A.** and Ryan, M. (2016) Impact of mining and industrial pollution on stream macroinvertebrates: importance of taxonomic resolution, water geochemistry and EPT indices for impact detection. *Hydrobiologia.*
21. Ryan M, Burgin S, **Wright IA,** (2015) Effects of wetland water source on a population of the Australian eastern long-necked turtle Chelodina longicollis, *Water, Air and Soil Pollution*, vol 226, no 12, [ORS ID: 239796]
22. **Wright IA,** McCarthy B, Belmer N, Price P, (2015) Subsidence from an underground coal mine and mine wastewater discharge causing water pollution and degradation of aquatic ecosystems, *Water, Air, and Soil Pollution*, vol 226, no 10, [ORS ID: 239437]
23. Belmer N, **Wright IA,** Tippler C, (2015) Urban geochemical contamination of high conservation value upland swamps, Blue Mountains Australia, *Water, Air, and Soil Pollution*, vol 226, no 10, [ORS ID: 239460]
24. Tippler, C., **Wright, I.A.,** Davies, P.J. and Hanlon, A. (2014) The influence of concrete on the geochemical qualities of urban streams. *Marine and Freshwater Research*, 65: 1009-1017.
25. Grella, C., **Wright. I.A.,** Findlay, S.J., and Jonasson, O. J. (2014) Geochemical contamination of urban water by concrete stormwater infrastructure: an epoxy resin coating may be an effective control treatment. *Urban Water Journal*.
26. Davies, P.J. and **Wright, I.A.** (2014) A review of policy, legal, land use and social change in the management of urban water resources in Sydney, Australia: a brief reflection of challenges and lessons from the last 200 years." *Land Use Policy*.
27. Tippler, C., **Wright, I.A.** and Hanlon, A. (2012) Is catchment imperviousness a keystone factor degrading urban waterways? A case study from a partly urbanised catchment (Georges River, south-eastern Australia). *Water, Air and Soil Pollution*. 223: 5331-5344.
28. Borchard, P., Eldridge, D.J. and **Wright, I.A.** (2012) Sarcoptes mange (Sarcoptes scabiei) increases diurnal activity of bare-nosed wombats (Vombatus ursinus) in an agricultural riparian environment. *Mammalian Biology*. 77: 244-248.
29. Graham, K., and **Wright, I.A.** (2012) The potential and reality of the Environment Protection Licensing system in NSW: the case of water pollution. *Environmental Planning and Law Journal.* 29: 359-372.
30. **Wright, I.A.,** Davies, P.J., Jonasson, O. J., and Findlay, S.J. (2011) A new type of water pollution: concrete drainage infrastructure and geochemical contamination of urban waters. *Marine and Freshwater Research*. 62: 1-7.
31. **Wright, I.A.,** Wright S.A., Graham, K. and Burgin, S. (2011) Environmental protection and management: a water pollution case study within the Greater Blue Mountains World Heritage Area. *Land Use Policy*. 28(1) 353-360.
32. Borchard, P., **Wright, I.A.** and Eldridge, D.J. (2010) Wombats and domestic livestock as potential vectors of Cryptosporidium and Giardia in an agricultural riparian area. *Australian Journal of Zoology*. 58(3): 150-153.
33. Davies, P.J., **Wright. I.A.,** Jonasson, O. J., and Findlay, S.J. (2010) Impact of concrete and PVC pipes on urban water chemistry. *Urban Water Journal*. 7(4): 233-241.
34. Borchard, P. and **Wright, I.A.** (2010) Bulldozers and blueberries: managing fence damage by bare-nosed wombats (Vombatus ursinus) at the agricultural-riparian interface. *Human-Wildlife Interactions.* 4 (2): 247-256.
35. Davies, P.J., **Wright, I.A.,** Jonasson, O. J., Findlay, S.J. and Burgin, S (2010) Impact of urban development on aquatic macroinvertebrates in south eastern Australia: degradation of in-stream habitats and comparison with non-urban streams. *Aquatic Ecology*, 44: 685-700.

36. Borchard, P. and **Wright, I.A.** (2010) Using camera-trap data to model habitat use by bare - nosed wombats (Vombatus ursinus) and cattle (Bos taurus) in a southeastern Australian agricultural riparian ecosystem. *Australian Mammalogy* 32: 16-22.
37. Borchard, P., **Wright, I.A**. and McArthur, C. (2009) Do common wombat (Vombatus ursinus) mounds influence terrestrial macroinvertebrate assemblages in agricultural riparian zones? *Australian Journal of Zoology* 57: 329-336.
38. **Wright, I.A.** and Burgin, S. (2009) Diel variation in chironomid (Diptera: Insecta) exuviae abundance and taxonomic richness in near-pristine upland streams of the Greater Blue Mountains World Heritage Area, South-Eastern Australia. *Aquatic Ecology*. 44: 131-141.
39. **Wright, I.A.** and Burgin, S. (2009) Effects of organic and heavy-metal pollution on chironomids within a pristine upland catchment. *Hydrobiologia* 635: 15-25.
40. **Wright, I.A.** and Burgin, S. (2009) Comparison of sewage and coal-mine wastes on stream macroinvertebrates within an otherwise clean upland catchment, south-eastern Australia. *Water, Air and Soil Pollution*. 204: 227-241.
41. **Wright I.A.** and Burgin, S. (2007) Species richness and distribution of eastern Australian lake chironomids and chaoborids. *Freshwater Biology*, 52: 2354-2368.
42. **Wright, I.A.**, and Cranston, P.S. (2000) Are Australian lakes any different? -Chironomid and Chaoborid exuviae from Lake McKenzie, a coastal temperate dune lake. *Verhandlungen Internationale Vereinigung fur Theoretische und Angewandte Limnologie*, (International Journal for Theoretical and Applied Limnology) 27: 303-308
43. Growns, J.E., Chessman, B.C., McEvoy, P.K. and **Wright, I.A.** (1995) Rapid assessment of rivers using macroinvertebrates: Case studies in the Nepean River and Blue Mountains, NSW. *Australian Journal of Ecology*, 20: 130-141.
44. **Wright, I.A.,** Chessman, B.C., Fairweather, P.G., and Benson, L.J. (1995). Measuring the impact of sewage effluent of an upland stream: the effect of different levels of taxonomic resolution and quantification. *Australian Journal of Ecology*, 20: 142-149.

Peer-reviewed conference proceedings

1. IA Wright, KG Morrison, MM Ryan, S Cusbert, JK Reynolds (2019) Elevated sodium concentrations in Australian drinking water supplies. IOP Conference Series: Earth and Environmental Science 344 (1), 012032

2. R Carroll, JK Reynolds, IA Wright (1019) Geochemical impact of urban development on fragile freshwater wetlands. IOP Conference Series: Earth and Environmental Science 344 (1), 012004

3. K Purdy, IA Wright (2019) Impact of concrete on riparian ecosystems.IOP Conference Series: Earth and Environmental Science 344 (1), 012033

4. L Robba, IA Wright (2019) The painted river project: Art meets science–communicating cultural transformation through community engagement. IOP Conference Series: Earth and Environmental Science 344 (1), 012015

5. T Rowlands, MM Ryan, A Estreich, IA Wright (2019) 'Swimmability': A key element for communities to safely engage with Australian urban rivers. IOP Conference Series: Earth and Environmental Science 344 (1), 012016

6. KG Morrison, JK Reynolds, N Belmer, IA Wright (2019) Ecological and geochemical impact of an underground colliery waste discharge to a river. IOP Conference Series: Earth and Environmental Science 344 (1), 012003

7. BS Green, R Carroll, KG Morrison, JK Reynolds, IA Wright (2018) Community triggers EPA action on coal mine river pollution. Proceedings of the 9th Australian Stream Management Conference, 12-15 August 2018

8. N Belmer, IA Wright (2018) Heavy metal contamination of water column from a coal mine waste water discharge resulting in mobilisation of metal contaminants to riparian vegetation. Wollangambe River, Blue Mountains. Proceedings of the 9th Australian Stream Management Conference, 12-15 August 2018

9. IA Wright, KG Morrison, E Hurst, M Ryan (2018) Water quality and ecological recovery of a mountain stream after 60 years of receiving sewage effluent. Proceedings of the 9th Australian Stream Management Conference, 12-15 August 2018

10. Phillip Lorenzelli, IA Wright and Peter Davies. (2018). What happens to the stream when the coal mine closes, Proceedings of the 9th Australian Stream Management Conference, 12-15 August 2018
11. Morrison K, Reynolds J, Wright I, 2018, Underground coal mining and subsidence, channel fracturing and water pollution : a five-year investigation, *Australian Stream Management Conference*, pp 689-696, [REDI ID: 253551]
12. Carroll R, Wright I, Reynolds J, 2018, Is geochemical contamination from urban development contributing to weed invasions in high conservation value wetlands?, *Australian Stream Management Conference*, pp 673-680, [REDI ID: 253544]
13. Geiger V, Date-Huxtable L, Ahlip R, Herberstein M, Jones D, May E, Rylands L, **Wright IA**, Mulligan J, (2016), Designing online learning for developing pre-service teachers' capabilities in mathematical modelling and applications, Mathematics Education Research Group of Australasia. Conference, pp 262-270, [REDI ID: 246309]
14. Belmer N, **Wright IA**, Tippler C, (2016) Urban swamp syndrome : degradation of a high conservation-value swamp from an urban catchment, Australian Stream Management Conference, [REDI ID: 243117]
15. Birtles P, Hoban A, Tippler C, Shoo B, Davies P, **Wright I**, (2015), Liveability and an urban creek : perspectives and dreams of residents who are not yet, *International Conference on Water Sensitive Urban Design* , [ORS ID: 240763]
16. Day, C., **Wright, I.A.**, St Lawrence, A., Setter, R. and Smith, G. (2014) Factors influencing deoxygenation following an unintended whole of water body herbicide treatment of aquatic weed cabomba in a natural wetland in the Blue Mountains, NSW, Australia, in Viets, G; Rutherfurd, I.D, and Hughes, R. (editors), Proceedings of the 7th Australian Stream Management Conference, Townsville, Queensland, Pages 291-299.
17. Sullivan, R., **Wright, I.A.**, Renshaw, A., and Wilks, M. (2014) The assessment of impacts from mining wastes on water quality and aquatic ecosystems using freshwater macroinvertebrate communities and novel bio-assay tests, in Viets, G; Rutherfurd, I.D, and Hughes, R. (editors), Proceedings of the 7th Australian Stream Management Conference, Townsville, Queensland, Pages 369-376.
18. Belmer, N., Tippler, C., Davies, P.J., and **Wright, I.A.** (2014) Impact of a coal mine waste discharge on water quality and aquatic ecosystems in the Blue Mountains World Heritage Area, in Viets, G; Rutherfurd, I.D, and Hughes, R. (editors), Proceedings of the 7th Australian Stream Management Conference, Townsville, Queensland, Pages 385-391.
19. Tippler, C., Findlay, S., **Wright I.A.**, Davies, P.J., vans, C. and Ahmed, M. (2014) Does seasonality influence macroinvertebrate communities in the temperate paradise of Sydney, in Viets, G; Rutherfurd, I.D, and Hughes, R. (editors), Proceedings of the 7th Australian Stream Management Conference, Townsville, Queensland, Pages 392-399.
20. Chircop, N., and **Wright I.A.** (2014) Water quality and ecological impacts of treated sewage effluent on a peri-urban stream, in Viets, G; Rutherfurd, I.D, and Hughes, R. (editors), Proceedings of the 7th Australian Stream Management Conference, Townsville, Queensland, Pages 463-468.
21. Grella, C., Tippler, C., Renshaw, A. and **Wright I.A.** (2014) Investigating the link between riparian weed invasion, riparian soil geochemistry and catchment urbanisation, in Viets, G; Rutherfurd, I.D, and Hughes, R. (editors), Proceedings of the 7th Australian Stream Management Conference, Townsville, Queensland, Pages 534-541.
22. Shield, K., Tippler, C. and **Wright I.A.** (2014) The invasive freshwater gastropods, Physa acuta and Potamopyrgus antipodarium: distribution in urban and non-urban streams in the Georges River catchment, in Viets, G; Rutherfurd, I.D, and Hughes, R. (editors), Proceedings of the 7th Australian Stream Management Conference, Townsville, Queensland, Pages 542-548.
23. St Lawrence, A., **Wright, I.A.**, McCormack, R.B., Day, C., Smith, G. and Crane, B. (2014) Bifenthrin pesticide contamination: impacts and recovery at Jamison Creek, Wenworth Falls, in Viets, G; Rutherfurd, I.D, and Hughes, R. (editors), Proceedings of the 7th Australian Stream Management Conference, Townsville, Queensland, Pages 558-567.
24. **Wright, I.A.**, Hanlon, A., and Davies, P.J. (2013) Ecosystem guidelines for the conservation of aquatic ecosystems of the Georges River catchment (south west Sydney). A method applicable to the Sydney basin. Submitted to State of Australian Cities Conference, 2013.
25. Knights, D., Beharrell, D. and **Wright, I.A.** (2012) Is it possible to have high frequency flow disturbance and high stream health? Results from a field survey in northern Sydney. Proceedings of 7th International Conference on Water Sensitive Urban Design Conference, Melbourne.

26. **Wright, I.A.**, Wallwood, N. Wolfenden, J. and Old, J. (2012) Are Australian Chironomids tolerant of water pollution? In Grove, J.R. and Rutherfurd, I.D (eds). Proceedings of the 6th Australian Stream Management Conference, Managing for Extremes, 6-8 February, 2012 Canberra, Australia, published by the River Basin Management Society p.p 533-539.
27. **Wright, I.A.** (2012) Coal mine 'dewatering' of saline wastewater into NSW streams and rivers: a growing headache for water pollution regulators. In Grove, J.R. and Rutherfurd, I.D (eds). Proceedings of the 6th Australian Stream Management Conference, Managing for Extremes, 6-8 February, 2012 Canberra, Australia, published by the River Basin Management Society p.p 206-213.
28. Tippler, C., **Wright, I.A.**, and Hanlon, A. (2012) Development of regional freshwater water quality and catchment guidelines for the conservation of aquatic ecosystems: a case study from the Georges River catchment. In Grove, J.R. and Rutherfurd, I.D (eds). Proceedings of the 6th Australian Stream Management Conference, Managing for Extremes, 6-8 February, 2012 Canberra, Australia, published by the River Basin Management Society p.p 519-525.
29. Davies, P.J., **Wright, I.A.**, Findlay, S.J. and Jonasson, O. J., (2010). Impact on stormwater runoff quality by the concrete drainage system. In, Stormwater 2010 Conference Proceedings of the 1st National Conference of the Stormwater Industry Association of Australia, 8-12 November 2010, Sydney Australia.
30. Davies, P. J., **Wright. I. A.**, Findlay, S. J and Jonasson, O. J. (2010). The effect of the in-transport process on urban water chemistry – an examination of the contribution of concrete pipes and gutters on urban water quality. In 'NOVATECH 2010 - Proceedings of the 7th International Conference on Sustainable techniques and strategies in urban water management'. Session 2.7 pp. 1-10. (GRAIE, Lyon, France) Available at (http://documents.irevues.inist.fr/bitstream/handle/2042/35843/32706-014DAV.pdf?sequence=1)
31. **Wright, I. A.**, Davies, P., Wilks, D., Findlay, S. and Taylor, M.P. (2007) Aquatic macroinvertebrates in urban waterways: comparing ecosystem health in natural reference and urban streams, in Wilson, A.L., Dehaan, R.L., Watts, R.J., Page, K.J., Bowmer, K.H., & Curtis, A. (eds.) *Proceedings of the 5th Australian Stream Management Conference. Australian rivers: making a difference*. Charles Sturt University, Thurgoona, New South Wales.
32. Hardwick, R.A., **Wright, I.A.**, Jones, H.A., Chessman, B.C. and Holleley, D. (1995) Rapid biological assessment of streams in the Blue Mountains, Australia: Characteristics of the Chironomidae fauna. In *Chironomids: From Genes to Ecosystems*, ed. Cranston, P.S. CSIRO, East Melbourne.

Non-peer reviewed conference proceedings

Davies, P.J., **Wright, I.A.**, Jonasson, O. J. and Findlay, S.J. (2009) Effects of concrete and PVC pipes on water chemistry, presented at *6th International Water Sensitive Urban Design Conference and Hydropolis*, 5–8 May 2009, Perth, Western Australia.

Supervision of HDR and honours research students

1. I co-supervised Michael Roberts (Macquarie University) 2006-2011. His PhD investigated eastern grey kangaroos and zoonotic pathogens in a protected water catchment. **PhD conferred 2011**.
2. I co-supervised the late Philip Borchard (Sydney University) 2006-2010. His PhD research examined wombats and riparian ecosystems. **PhD conferred 2011**.
3. I co-supervised Peter Davies 2007-2011 (Macquarie University). His PhD conducted research on sustainable urban waterway rehabilitation and management by local Government **PhD conferred 2012**.

4. I co-supervised Michelle Ryan (University of Western Sydney) PhD research on turtle ecological research in recycled water dams and wetlands on UWS Hawkesbury campus (2007-present). **PhD conferred 2014.**

5. I co-supervised Nicole Wallwood's (University of Western Sydney) Master of Science research project (2009/10) on the topic of organic and industrial water pollution on freshwater ecosystems using Chironomidae exuviae as biological indicators. **MSc. conferred 2010.**

6. I was principal supervisor of Katie Shield's (University of Western Sydney) honours research on the impact of urban development on freshwater ecosystems using two invasive gastropod snails as pollution indicators. **First Class Honours was awarded in 2014.**

7. I was principal supervisor of Chiara Grella's (University of Western Sydney) honours research on the impact of urban development (according to the level of impervious urban surfaces) on riparian weeds, and the link to mineral and nutrient levels in the riparian soil. **First Class Honours was awarded in 2014.**

8. I was principal supervisor of Rebecca Sullivan's (University of Western Sydney) honours research on the impact of two different levels of heavy-metal and geochemical pollution (from mining, metal smelting and coal fly-ash disposal) on freshwater ecosystems using stream macroinvertebrates and investigating novel bioassay techniques. **First Class Honours was awarded in 2015.**

9. I was principal supervisor of Naomi Chircop's (University of Western Sydney) honours. Her research is examining the link between degraded riparian vegetation, invasive weeds and contamination from concrete stormwater infrastructure. **Honours was awarded in 2016.**

10. I was principal supervisor of Rhiannon Khoury's (University of Western Sydney) honours research on the invasive freshwater snail (New Zealand Mudsnail) invading Blue Mountains upland swamps. **Honours was awarded in 2016.**

11. I was principal supervisor of Nakia Belmer's (University of Western Sydney) honours research on the ecological and water quality impact of urban development on Blue Mountains Upland Swamps. **Honours was awarded in 2016.**

12. I was principal supervisor of Phillip Price's (University of Western Sydney) honours research on the ecological impact of active and closed coal mines. **Honours was awarded in 2016.**

13. I am currently principal supervisor of Nakia Belmer (Western Sydney University). His full-time PhD research involves the water quality and ecological assessment of underground coal mines in the Sydney basin.

14. I am currently principal supervisor of Rani Carroll's (Western Sydney University) PhD. I previously was principal supervisor of her Master of Research. Her PhD research investigates the effects of urban geochemical contamination on critically endangered Blue Mountains Upland Swamps.

15. I currently co-supervise Carl Tippler's part-time PhD. (Macquarie University) with Dr Peter Davies. This research investigates ustainable urban waterway management and will include water chemistry, freshwater ecology and policy and management elements. This started in 2013.

16. I co-supervised Phillip Lorenzilli's Master of Research (Macquarie University) with Dr Peter Davies 'Metal Pollution from Conventionally Treated Acid Mine Drainage in a Naturally Acidic Freshwater Stream'.

17. I co-supervised A. Ali's PhD. (Macquarie University) with Dr Peter Davies and Prof. Strezov. This research investigates coal mining and coal seam gas mining on water quality and river sediment in the Sydney basin.

Selection of unpublished reports

1. October 2017. Affadavit for Land and Environment Court. 'Review of impact of water discharges from Springvale Colliery on the water quality and aquatic ecology'.
2. 2016 Audit of the Sydney Drinking Water Catchment. I wrote the chapters on water quality, cyanobacterial blooms, nutrient loads and macroinvertebrates. (https://www.parliament.nsw.gov.au/lc/papers/DBAssets/tabledpaper/WebAttachments/71475/Sydney%20Catchment%20Audit%20Vol%202.pdf)
3. Investigation of upper Wollangambe River water quality, sediment quality and biodiversity: An Assessment of the impact of the July 2015 Clarence Colliery sediment spill for the Australian Commonwealth Government, Environment Australia. October 2016
4. Unpublished book chapter (2013) 'Water Pollution in the Gardens of Stone National Park and nearby waterways of the western Blue Mountains area' (in review) Chapter of upcoming bushwalking and environmental history book on the Gardens of Stone area.
5. North Sydney Report (November 2012) 'Review of North Sydney Council's Water Quality Monitoring Program 1999 – 2011', co-authored with Carl Tippler.
6. Penrith Council Report (August 2012) 'Investigation of orange discolouration on the bed of wetland surface waters at Claremont Meadows'.
7. Ryde Council Report (September 2012) 'Strategic Overview of the Water Quality Monitoring Program' co-authored with Equatica environmental engineering consultants.
8. Submission to NSW EPA review of Westcliff waste discharge (October 2012) 'Investigation of water quality and ecosystem health in the upper Georges River: focus on the influence of West Cliff wastewater discharge and recommendations for new discharge conditions for EPL 2504'.
9. Blue Mountains City Council Report (July 2012) 'Macroinvertebrate Data and Monitoring Program 2009-2010' .
10. Hornsby Council Report (December 2011) 'Review of Hornsby Shire Council's Aquatic Ecosystem Program (2002-7) Macroinvertebrates and Algal Diatoms Supplementary Report: Additional Reference Site Data'.
11. Blue Mountains Conservation Society Report. (October 2011) 'Investigation of water quality in the upper Coxs River: focus on the influence of Wallerawang Power Station wastewater discharges'.

12. Sydney Water report. (September 2011) ‘Review of options to improve Sydney Water’s wastewater system at Winmalee (aquatic ecology) Independent review for Sydney Water Wet Weather SewerFix Program’.
13. Ku-ring-gai Council Report (June 2011) ‘Assessment of Aquatic Macroinvertebrates and Aquatic Ecosystem Health in Ku-ring-gai Council waterways’ .
14. NSW Land and Environment Court Report, (March 2011) ‘Review of Duralie Extension Project Environmental Assessment: focus on water quality and aquatic ecology / biodiversity’.
15. Bankstown Council Report (February 2011) ‘Review of Bankstown City Council’s Water Quality Monitoring Program 1997-2009’.
16. Hornsby Council Report (February 2011) ‘Review of Hornsby Shire Council’s Aquatic Ecosystem Program (2002-2007) Macroinvertebrates and Algal Diatoms’.
17. Penrith Council Report (June 2010) ‘Assessment of Aquatic Macroinvertebrates and aquatic ecosystem health in Penrith City Council waterways’.
18. Personal submission to the NSW Planning Minister’s Planning Assessment Commission into the 30 year approval for further mining at the Bulli Seam (February 2010). (This submission was supported by an oral presentation).
19. University of Western Sydney Report (2009) ‘Stream studies featuring the Wolgan River & Carne Creek 2009’. Prepared by UWS Native and Pest Animal Unit for Wolgan Valley Emirates Estates. (Co-author).
20. Personal submission to the Independent Review of the Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC Act) (2009).
21. Sydney Water (2004) Environmental performance of Sydney Water’s inland STP: macroinvertebrates. Part of Sydney Water’s Annual Environmental Indicators compliance report. (Co-author).
22. Sydney Water (2003) Environmental performance of Sydney Water’s inland STP: macroinvertebrates. Part of Sydney Water’s Annual Environmental Indicators compliance report. (Co-author).
23. Australian Water Technologies (2003) Fisheries assessment of proposed housing development at Warriewood. Prepared for Australand.
24. Sydney Water (2002) Environmental performance of Sydney Water’s inland STP: macroinvertebrates. Part of Sydney Water’s Annual Environmental Indicators compliance report. (Co-author).
25. Sydney Water (2002) Environmental response to WaterPlan 21 initiatives in the Hawkesbury-Nepean river system. (I was co-author to part of this report).
26. Australian Water Technologies (2001) Ecosystem health of waterways in the Lane Cove Catchment. Consultancy report for Ku-ring-gai Council. (Co-author).
27. Australian Water Technologies (2002) Pressure-Biota-Habitat report for the Hawkesbury-Nepean catchment. Consulting Report for NSW Department of Land and Water Conservation. (Co-author).
28. Sydney Water (2000) Environmental methodology for assessing sewer overflow performance, for the Sydney Water SCAMP overflow modelling and assessment program. (Co-author).

Employment History - Environmental Consulting

From 2009 to 2015 I ran a small (sole trader) environmental consulting business - 'Dr Ian A Wright Environmental Consulting'. Since then I have continue to undertake some industry consulting projects through Western Sydney University's Research Engagement, Development and Innovation group. Through my consulting projects I have provided expert advice and assistance on water science projects to a broad range of industry clients. The nature of my consulting is very diverse and has included independent reviews of information, sampling and laboratory analysis of freshwater invertebrates, multivariate and univariate analysis and reporting of freshwater ecology and water quality data. My clients and projects over the last eight years has included:

- **Ku-ring-gai Council** (managing, data analysis and reporting a species-level macroinvertebrate monitoring project)
- **Hornsby Council** (review, data analysis and reporting historic five year macroinvertebrate and algal diatom data; training and expert assessment of future assessment design)
- **Penrith Council** (sampling, macroinvertebrate identification, data analysis and reporting 2010 macroinvertebrate monitoring program; training staff in water sampling for prosecution)
- **North Sydney Council** (review, data analysis and reporting historic 12 year water quality assessment)
- **Bankstown Council** (review, data analysis and reporting historic 12 year water quality data)
- **Blue Mountains Council** (review, data analysis and reporting historic 10 year macroinvertebrate data)
- **Ryde Council** (review, data analysis and reporting historic seven year water quality and stream ecology data). This project was undertaken as a sub-consultancy through Equatica Consulting.
- **Georges River Combined Councils Committee** (delivery of training workshop on macroinvertebrate sampling methods; preparing and delivering a presentation on sustainable water management in the Georges River area)
- **NSW Environmental Defenders Office** (expert witness for multiple EIA assessment cases and four major water pollution court cases). The majority of these cases has involved *pro bono* work.
- **Sydney Water**, I have provided Sydney Water with strategic advice on stormwater and urban water management and assisted with the SewerFix Wet Weather Alliance (independent expert review of sewer overflow options). My review was used to provide advice to Blue Mountains stakeholders and Sydney Water staff on a number of engineering options for sewage overflow abatement.
- **2016 Commonwealth Government (Environment Australia)** May to October 2016. I conducted an independent assessment of the impact of the July 2015 Clarence Colliery sediment spill on the Wollangambe River, Blue Mountains World Heritage Area.
- **2017 Victorian Government –** I was commissioned to investigate the potential water quality impact of the demolition and on-site disposal of a concrete mass dam on the Nicholson River, East Gippsland, Victoria. I collected samples of the concrete from the dam wall and exposed

the concrete, in various size classes, to water collected from the Nicholson River. I then conducted a laboratory assessment of changes in water chemistry due to dissolution of the concrete. This project was conducted as sub-consultancy through Alluivium Consulting.

- **2016/2017 Independent Audit of Sydney's drinking water catchments and storages.** The audit is a statutory requirement under the Water NSW Act 2014 (NSW). Section 42 of the Water NSW Act 2014 requires that an audit is conducted every three years. The audit involves an assessment of the catchment and water quality health of Sydney's declared water catchments. The report was presented to the Minister for Land and Water who subsequently tabled the report in both NSW Houses of Parliament in August 2017. My role was to conduct the water quality, cyanobacteria, nutrient load, macroinvertebrate and pollution modelling chapters. This project was conducted as sub-consultancy through Alluivium Consulting.
- **2017 NSW Planning and Environment.** I have been enagaged to provide an independent expert assessment of possible water pollution from an industry development site in Western Sydney. The details of this case are confidential as it is on-going investigation and lilely to involve a court hearing.

Employment History - Postdoctoral Fellowship

- **February 2007 – February 2010.Three year Aquatic Ecology Postdoctoral Research Fellow, University of Western Sydney.**

My Fellowship research focussed on scientific research projects associated with urban and natural waterways, wildlife, conservation of biodiversity, water pollution, sustainability and water reuse / recycling. Part of my research involved co-supervision and collaboration with several PhD and other postgraduate students at University of Western Sydney (UWS), Macquarie University and Sydney University. My post-doctoral research resulted in more than 12 peer-reviewed research publications.

Employment History - Roles in science and industry (1989 – 2007)

- **June 2006 – Jan. 2007 (part-time) Principal Environmental Scientist, Ku-ring-gai Council.**

I was the Principal Environmental Scientist for Ku-ring-gai Council, I provided scientific advice to Council on a range of environmental projects and activities. I also provided leadership to a small environmental team. I continued with a number of my urban waterway research projects from Ku-ring-gai Council in my UWS postdoctoral research (see CV 'publications').

- **July 2005 – December 2006 Senior Scientist (Collaborative Research), Sydney Catchment Authority (on secondment from Sydney Water).**

My role was to coordinate three collaborative scientific research projects between the Sydney Catchment Authority and research partners. The projects involved the ecology of Eastern Grey Kangaroos in the Warragamba catchment area (with Macquarie University) and *Cryptosporidium* projects (investigating the sources, genotypes and infectivity of *Cryptosporidium*) in Sydney Catchment Authority catchment areas, also with Macquarie University.

March 2005 – June 2005 Environmental Policy Analyst, Sydney Water

This position was a four month secondment to Sydney Water Regulation and Pricing group where I assisted with the coordination of regulatory stakeholder relationships, particularly in the key corporate areas that included Sydney Water's Operating Licence, Bulk Water Supply Agreement with the Sydney Catchment Authority. I was also involved with preliminary negotiations for a Water Access Licence with NSW Department of Natural Resources.

- **April 2000 – March 2005 Senior Team Leader of Aquatic Ecology, Sydney Water**

For five years I was leader of the Sydney Water freshwater ecology group. The team of eight staff provided technical advice and scientific assessment of impacts of Sydney Water's (and external clients) activities and operations on aquatic ecosystems, particularly from sewerage treatment plant (STP) discharges into streams and rivers. This group had strong expertise in the field of aquatic ecology, particularly in the assessment of fish, macroinvertebrates, riparian plants and water quality. The group ran a freshwater macroinvertebrate laboratory that had a collection of specimens that was of museum quality. The laboratory and procedures were accredited by NATA (National Association of Testing Authorities) to conduct species-level assessment of macroinvertebrates, one of very few in Australia.

- **July 1999 – June 2000 Environmental Scientist and Team Leader, Sydney Water**

I was team leader for the sewerage overflow planning project ('SCAMP', Sewerage Catchment Area Management Planning). This project produced detailed sewerage system plans to improve the overflow and thus environmental performance of the sewerage system in the vicinity of Sydney Harbour My role was to develop, test and improve the environmental assessment component, with a small project team, in conjunction with my planning and engineering colleagues.

- **October 1998 - June 1999 Environmental Scientist, Priority Sewerage Program, Sydney Water**

I assisted with the development of 'Environmental Impact Assessments' that were conducted on seven unsewered urban areas in the greater Sydney region. All areas relied on on-site sewage disposal systems such as septic tanks with absorption trenches, aerated wastewater treatment systems and 'pump-out' systems. My role in the project was to manage a number of consultants' studies that collected environmental data and generated information for the program.

- **June 1996 - October 1998 Full-time Ph.D. student, Australian National University (ANU), Canberra**

I was a visiting scientist at CSIRO Division of Entomology and a full time PhD student at ANU. I subsequently transferred the PhD to the University of Western Sydney to complete on a part-time basis.

- **October 1997 - March 1998 Environmental Scientist (Sydney Water)**

Regional Environmental Scientist with Sydney Water, Greater Western Region. I was involved in the production and internal review of environmental impact statements (EISs) produced to assess the current environmental impact of sewerage overflows, for each of Sydney's sewerage systems 'Sewerage Overflow Licensing Project'. This included working for the Sydney Water Utilities Division, in a small project team, writing sections of the Sydney-wide summary EIS document.

- **October 1996 - November 1997 Private consultancy – Development of Education Materials.**

I developed a guide to stream macroinvertebrates of the Blue Mountains region for the Hawkesbury-Nepean Catchment Management Trust and Blue Mountains Catchment Management Committee. I developed a draft document, collected and photographed insect and other invertebrate specimens, organised two groups of community participants to 'field-test' the draft, and incorporated comments into the final text.

- **March 1996 - June 1996 Environmental Scientist, Sydney Water**

Environmental Policy Analyst with Sydney Water Environmental Branch, Head Office. I was involved in quality control and internal review of environmental impact statements produced by external consultants as part of the 'Sewerage Overflow Licensing Project'.

- **April 1994 - March 1996 Catchment Protection Officer**

Catchment Protection Officer at the Catchment Services Group, Sydney Water. I advised the group on water quality issues and reviewed water quality monitoring projects, commissioned by Catchment Services, in the Warragamba, Metropolitan and Blue Mountains water supply catchment areas. I chaired a 'Water Quality Working Group' within the Catchment Services Group. I was also involved in other catchment management duties including bushfire management, pest control, soil conservation, and public relation duties.

I co-ordinated the development of the Warragamba Catchment Plan of Management. This was done on behalf of both Sydney Water and the NSW National Parks and Wildlife Service (joint sponsors of the plan). This involved research, liaison with dozens of government, industry and community stakeholders. Preparation of the plan involved policy development and writing the initial draft document. I also overviewed the water quality components in the two other Plans for the Blue Mountains and the Metropolitan storage catchment areas.

- **May 1989 - April 1994 Scientific Officer, Sydney Water**

Scientific Officer with the Stream Studies Section of Sydney Water, and the consulting arm Australian Water Technologies. My role included undertaking research and routine stream ecology and water quality projects. Projects included the study of macroinvertebrate, fish, and water quality indicators (chemical, physical and microbiological). I was also involved in the establishment of the macroinvertebrate laboratory at AWT and responsible for leadership of projects that measured the impact of sewage effluent and urban runoff on small streams in the Blue Mountains region.