Encouraging signs of ecological recovery in a river polluted with coal mine wastes within the Blue Mountains world heritage area.

Callum Fleming[1], Nakia Belmer[1], Jason Reynolds[1] and Ian Wright.[1]

1 School of Science, Western Sydney University, Bourke St, Richmond NSW, 2753. Callum Fleming (callumfleming27@gmail.com*), Nakia Belmer (bayern11@tpg.com.au), Jason Reynolds (j.reynolds@westernsydney.edu.au), Ian Wright (i.wright@westernsydney.edu.au).*

Key Points

- Environmental regulation of coal mine wastes has been improved to reduce water pollution impacts in the Wollangambe River, located within the Greater Blue Mountains World Heritage Area.
- Levels of contaminants (salinity, nickel, zinc) have decreased, and macroinvertebrate abundance and richness has increased in the Wollangambe River comparing across 2013 and 2020.
- Discharge limits on contaminants in Environment Protection Licenses (EPL's) heavily influence water quality and river ecology in streams receiving wastes.
- To promote ecological recovery in polluted streams, appropriate discharge limits are needed that match the ANZECC guideline values for aquatic ecosystem protection.

Abstract

Coal mine wastewater is discharged to the Wollangambe River, located within the Greater Blue Mountains World Heritage area of New South Wales (NSW) Australia. Degradation of water quality and river ecology within the Wollangambe River has been recorded in past research. Since these studies, the NSW EPA have enforced updated environmental regulation of coal mine wastes. To quantify water quality and river ecology, measures of salinity, metals such as nickel, zinc, as well as total abundance and richness of macroinvertebrate families were collected. Comparing current data to past data has showed improvements of water quality and signs of ecological recovery in the Wollangambe River 20km past the wastewater discharge. Levels of contaminants in the water column such as salinity, nickel, and zinc have reduced while macroinvertebrate abundance and richness has increased. Changes to discharge limits of coal mine wastewater to match the ANZECC guideline values for ecosystem protection can promote the recovery of water quality and river ecology in polluted streams. Environmental regulation of many coal mine waste discharges can be improved to reduce water pollution impacts in streams.

Keywords

Coal, mine, pollution, metals, macroinvertebrates, river, ecology, recovery.

Introduction

Coal mining and the discharge of resulting wastewater to the environment results in many adverse environmental impacts including water pollution and ecosystem degradation in rivers (Tiwary 2001). Many waterways that receive coal mine effluent are subject to water pollution through increases of contaminants such as salts and heavy metals such as nickel and zinc (Younger 2004). Heavy metals can bioaccumulate in and become toxic to river biota, resulting in ecosystem degradation and loss of biodiversity (Belmer 2019, Wright 2017, Giam 2015).

One example of a stream subject to water pollution impacts from coal mining is the Wollangambe River, which receives coal mine wastewater from Clarence Colliery. Past studies found degradation of water quality with contaminants such as nickel and zinc increasing in the water column (Belmer 2014). Additionally, adverse impacts to river ecology were found, with macroinvertebrate abundance decreasing by up to 90% (Wright 2017). Macroinvertebrates are commonly used as ecological indicators to assess stream health, with certain species sensitive to pollution, such as the EPT groups, Ephemoptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies) (Pond 2008).

Discharge of coal mine wastewater to streams in NSW, Australia is licensed and regulated by the NSW EPA, through an Environment Protection License (EPL). This license contains discharge limits for contaminants such as nickel and zinc. However, often these EPL's contain discharge limits that far exceed the ANZECC guideline values for aquatic ecosystem protection, which can result in water pollution (ANZECC 2000, Graham and Wright 2012, Belmer 2020, Fleming 2021). Clarence Colliery was issued a new EPL in 2016 that included discharge limits that matched the ANZECC guideline values for ecosystem protection (EPA 2020). This study aims to investigate water quality and river ecology in the Wollangambe River, and to assess the effectiveness of environmental regulation by comparing to past data.

Methods

Study area

The Wollangambe River lies within the Greater Blue Mountains World Heritage area, containing high conservation value land and biodiversity which is protected with layers of legislation and regulation (POEO 1997, NPWS 1974). The area contains many rare and threatened native flora and fauna, Aboriginal sites, and geological formations (NPWS 2001, DECC 2009). The Wollangambe River is widely used for recreational activities such as canyoning, bushwalking, and swimming. The Wollangambe stretches for 57km before entering the Colo River, a declared wild river which winds 39km before reaching the Hawkesbury River near Lower Portland.

Coal mine wastewater is discharged to the Wollangambe River from Clarence Colliery, an underground coal mine located in Newnes State Forest, on the border of the Greater Blue Mountains World Heritage Area. Clarence Colliery has been actively mining coal since 1980 (Cohen 2002). The discharge of coal mine wastewater to the Wollangambe River is regulated by the NSW EPA under the Protection of the Environment Operations (1997) Act, and EPL number 726 (POEO 1997, EPA 2020).

Water quality and aquatic ecology

Water sampling was conducted over two sampling periods: 2013 and 2020. The sampling area was designed to measure water pollution impacts up to 20km in the Wollangambe River, within the Greater Blue Mountains World Heritage Area. Water quality and macroinvertebrate communities were investigated across three sampling sites, upstream of the waste discharge (REF), downstream of the waste discharge (WSF), and 20km downstream in the Greater Blue Mountains World Heritage Area (WNP) (Figure 1).

Water quality and river ecology of the Wollangambe River were investigated over three sampling visits in both 2013 and 2020. To determine water quality, field meters were used to measure five replicates on each sampling visit of temperature and dissolved oxygen (YSI ProODO meter) as well as pH and salinity as electrical conductivity (TPS WP81 meter). Duplicate grab water samples were also collected on each sampling visit, chilled, and delivered to a NATA accredited laboratory (Envirolab Sydney) for analysis of heavy metals such as nickel and zinc using standard methods (APHA 1998).

Macroinvertebrate samples were collected at each site using the kick sampling method. An aquatic net was placed into the stream, followed by disturbing detritus and rocks for 30 seconds in a 30cm-by-30cm area, for five replicates. Contents of the net are then placed into a sorting tray, where macroinvertebrates are placed and stored in a sampling bottle with 70% ethanol. Macroinvertebrate samples were then taken to the laboratory and identified to family level using a stereomicroscope (ZEISS Stemi305). Data for water quality and macroinvertebrates was processed in Microsoft Excel using one-way ANOVA and summary statistics.

Figure 1. Map of the study area and sampling sites (A), Clarence Colliery (B), and the Wollangambe River at site WNP (C).

Results

Macroinvertebrate abundance and richness within the Wollangambe River at site WNP has increased comparing 2013 to 2020 data. Abundance has increased from 11.6 to 84.7, and richness has increased from 4.4 to 12.8. The richness and abundance of pollution-sensitive EPT macroinvertebrate families within site WNP also increased, with EPT richness increasing from 1.8 to 5.6, and EPT abundance from 5.9 to 21 (Table 1, Table 2, Figure 2).

The current study in 2020 showed macroinvertebrate abundance and richness at site WNP to be higher than the reference site (REF). Macroinvertebrate abundance at REF was 59.9, and 84.7 at WNP. Macroinvertebrate richness was 8.8 at REF, and 12.8 at WNP.

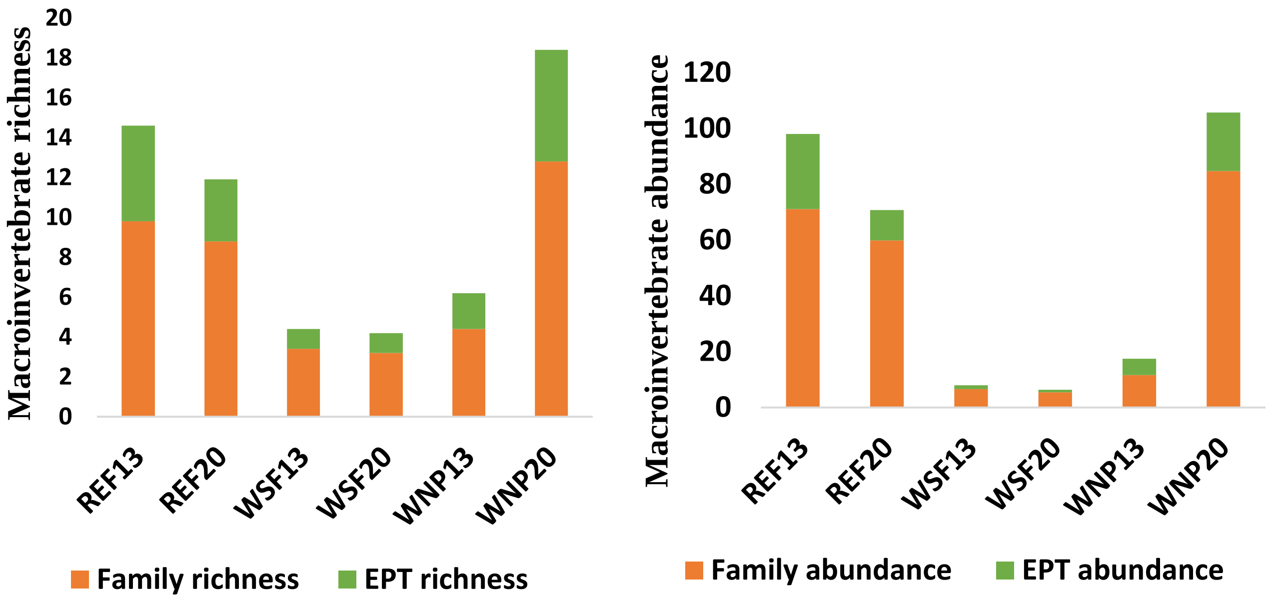

Figure 2. Macroinvertebrate richness (left) and macroinvertebrate abundance (right) across sampling sites REF, WSF, and WNP in the Wollangambe River across 2013 and 2020. Family richness/abundance is coloured orange, and EPT richness/abundance is coloured green.

Table 1. 2013 Data for water quality and river ecology in the Wollangambe River.

2013 Data		REF		WSF		WNP	
	p value (*f*-value)	Range	Mean (Median)	Range	Mean (Median)	Range	Mean (Median)
Temperature (°c)	0.0143 (4.434)	9.2-18	13.9 (14.6)	12.7-17.8	16.1 (17)	9.4-18.8	15.56 (17)
Dissolved oxygen (% saturation)	<0.001 (15.08)	83-99.8	95.3 (96.9)	72.2 (105.9)	94.7 (100.3)	92.4 (124.1)	105.1 (101.9)
pH (pH units)	<0.001 (222.47)	4.9-6.3	5.5 (5.4)	6.9-7.3	7.08 (7.1)	6.4-6.94	6.62 (6.64)
Electrical conductivity (µS/cm)	<0.001 (231.37)	23.5-36	29.4 (28.7)	252-488	378.4 (386)	106.2-326	212.2 (207)
Nickel µg/L	<0.001 (181.63)	Bd.-2	0.7 (Bd.)	78-141	101.5 (93.5)	36-48	41.1 (40)
Zinc µg/L	<0.001 (170.8)	2.5-7	3.1 (2.5)	94-180	126 (122.5)	40-64	50.1 (48.5)
Macroinvertebrate richness	<0.001 (37.26)	8-12.	9.8 (9.5)	3-4.	3.4 (3)	1-8.	4.4 (4)
Macroinvertebrate abundance	<0.001 (13.72)	27-149.	71.1 (60)	4-9.	6.6 (7)	3-38.	11.6 (9.5)
EPT richness	<0.001 (26.75)	3-8.	4.8 (4.5)	0-2.	1 (1)	0-3.	1.8 (2)
EPT abundance	<0.001 (11.23)	7-52.	26.9 (22.5)	0-3.	1.4 (1)	0-21.	5.9 (5)

Table 2. 2020 Data for water quality and river ecology in the Wollangambe River.

2020 Data		REF		WSF		WNP	
	p value (*f*-value)	Range	Mean (Median)	Range	Mean (Median)	Range	Mean (Median)
Temperature (°c)	<0.001 (11.92)	14.2-17.4	16.2 (16.65)	16-19.4	17.5 (17.6)	15.7-18.5	17.2 (17.4)
Dissolved oxygen (% saturation)	<0.001 (26.1)	86.3-94	90.7 (91.3)	66.8-90.3	83.4 (86.9)	90.5-92.5	91.7 (91.7)
pH (pH units)	<0.001 (43.54)	4.7-6.9	5.4 (5.1)	6.4-11.9	8.6 (7.5)	4.8-7.1	6.2 (6.4)
Electrical conductivity (µS/cm)	<0.001 (1026.3)	24.4-34.8	32.3 (33.3)	253.1-338.1	294.1 (300.1)	131.7-209.3	158.8 (149.9)
Nickel µg/L	<0.001 (38.9)	Bd.-2	0.6 (Bd.)	23-90	42.6 (33.5)	7-12.	9.2 (9)
Zinc µg/L	<0.001 (62.68)	1-9.	3.6 (2)	34-100	60.6 (56.5)	10-14.	12.1 (12.5)
Macroinvertebrate richness	<0.001 (14.87)	3-13.	8.8 (9.5)	2-4.	3.2 (4)	9-19.	12.8 (12.5)
Macroinvertebrate abundance	<0.001 (12.2)	28-136	59.9 (49.5)	4-9.	5.4 (5)	43-160	84.7 (85.5)
EPT richness	<0.001 (16.98)	0-7.	3.1 (3.5)	0-2.	1 (1)	4-7.	5.6 (5.5)
EPT abundance	0.0018 (8.45)	0-31	10.9 (11)	0-2	1 (1)	9-36.	21 (17.5)

Concentrations of contaminants in the Wollangambe River including salinity, nickel, and zinc have decreased in comparing water quality data from 2013 with 2020 (Table 1, Table 2). Within the Greater Blue Mountains World Heritage Area, 20km downstream past the mine discharge point (site WNP) signs of water quality recovery are seen. Salinity of the water column has reduced from 212.2 µs/cm in 2013 to 158.8 µs/cm in 2020 (Table 1). Levels of nickel have decreased from 41.1 to 9.2 µg/L. Similarly, zinc concentration at site WNP has reduced from 50.1 to 12.1 µg/L (Figure 3).

During both 2013 and 2020 sampling periods, pH and temperature increased in the Wollangambe River after the coal mine discharge. In 2013, pH increased from 5.5 at REF to 6.62 at WNP. In 2020, pH increased from 5.4 at REF to 6.2 at WNP. In 2013, water temperature increased from 13.9°c at REF to 15.56 °c at WNP. In 2020, water temperature increased from 16.2 °c at REF to 17.2 °c at WNP (Table 1, Table 2).

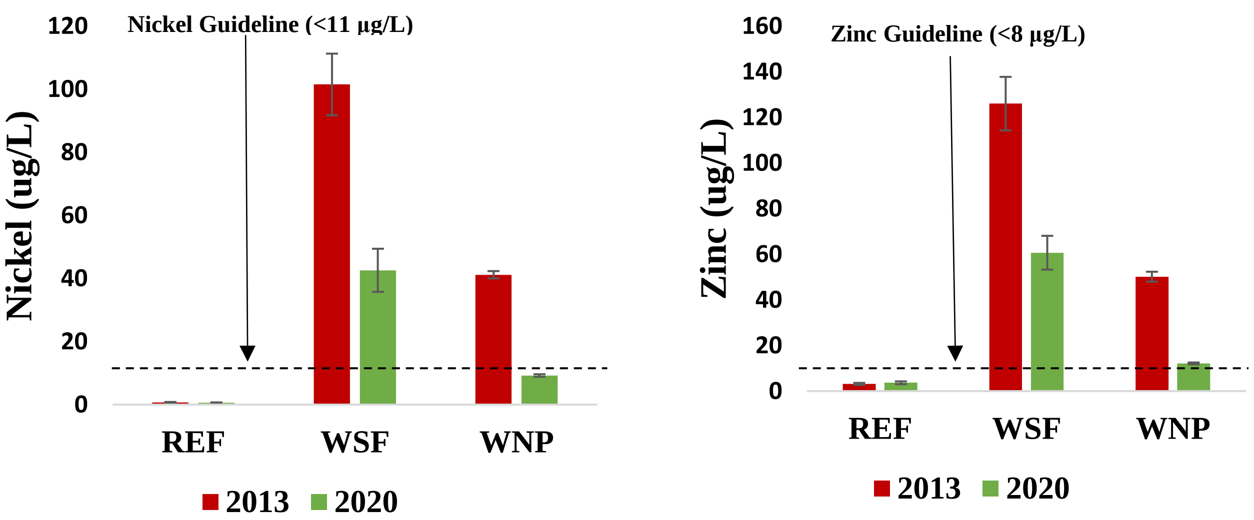

Figure 3. Nickel concentration (µg/L) on the left, and zinc concentration (µg/L) on the right across sampling sites REF, WSF, and WNP in the Wollangambe River. 2013 data is coloured red, and 2020 data is coloured green.

Discussion

Water pollution previously investigated in a 2013 study of the Wollangambe River found adverse impacts to water quality with salinity increasing from 29.4 µs/cm at the reference site to 212.2 µs/cm 20km downstream at site WNP (Belmer 2014). In comparing metals across sites REF and WNP, levels of nickel in the Wollangambe River increased from 0.7 to 41.1 µg/L, and zinc increased from 3.1 to 50.1 µg/L. Degradation of macroinvertebrate communities were also recorded comparing sites REF and WNP in 2013. Macroinvertebrate abundance decreased from 71.1 to 11.6, and macroinvertebrate richness decreased from 9.8 to 4.4. EPT family abundance decreased from 26.9 to 5.9, and EPT family richness decreased from 4.8 to 1.8.

Levels of contaminants in the Wollangambe River such as salinity, nickel, and zinc have decreased from 2013 to 2020. In the water column of the Wollangambe River at site WNP, concentrations of salinity have decreased from 212.2 µs/cm to 158.8 µs/cm. Concentrations of nickel have decreased from 41.1 to 9.2 µg/L, and zinc has fallen from 50.1 to 12.1 µg/L (Table 1, Table 2, Figure 3). The reduction of hazardous metals and salinity has contributed to improved water quality in the Wollangambe River. Signs of ecological recovery are seen in the Wollangambe River at site WNP, with macroinvertebrate abundance increasing from 11.6 in 2013 to 84.7 in 2020. Macroinvertebrate richness also increased from 4.4 in 2013 to 12.8 in 2020. Abundance and richness of pollution sensitive EPT groups increased, with EPT family richness increasing from 1.8 to 5.6, and EPT family abundance from 5.9 to 21 (Table 1, Table 2, Figure 2). These increases in macroinvertebrate abundance and richness suggest signs of ecological recovery in the Wollangambe River, following from water pollution impacts researched previously in 2013.

The driver for the changes seen in water quality and aquatic ecology of the Wollangambe River is likely the updated EPL and discharge limits for Clarence Colliery. The updated licence includes discharge limits that match the ANZECC guideline values for ecosystem protection. For example, in 2013, the old discharge limit for zinc at Clarence Colliery was 2500 µg/L, and the updated limit was changed to 8 µg/L (ANZECC 2000, EPA 2013, 2020). Additionally, nickel previously had no discharge limit, and is now included with a discharge limit of 11 µg/L. Effective environmental regulation is needed to decrease water pollution impacts in streams receiving coal mine wastewater. Through adequate licencing, ecological recovery can occur in streams polluted by coal mine wastewater.

Conclusions

Adverse impacts to water quality and aquatic macroinvertebrates in the Wollangambe River have been recorded in past studies. Since these studies, the NSW EPA has updated the EPL for Clarence Colliery, to include new discharge limits on contaminants that match the ANZECC guidelines for aquatic ecosystem protection. This current study investigated the effectiveness of the new environmental regulation, recording signs of recovery in water quality and aquatic macroinvertebrate communities of the Wollangambe River in the Greater World Heritage Area. Environmental regulation heavily influences the water quality and river ecology of waterways receiving coal mine wastewater discharge. The changes made to discharge limits in the EPL for Clarence Colliery have supported water quality and ecological recovery in the Wollangambe River. Discharge limits on contaminants such as nickel and zinc in EPL's should match the ANZECC guideline values for aquatic ecosystem protection. By improving environmental regulation of waste discharges to streams, water pollution impacts can be reduced.

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References

ANZECC (Australian and New Zealand Environment and Conservation Council). (2000). Australian and New Zealand guidelines for fresh and marine waters. Canberra: Australian and New Zealand Environment and Conservation Council. https://www.waterquality.gov.au/sites/default/files/documents/anzecc-armcanz-2000-guidelines-vol1.pdf

APHA (American Public Health Association). (1998). Standard methods for the examination of water and wastewater (20th ed.). Washington, DC: American Public Health Association.

Belmer, N., Tippler, C., Davies, P. J., & Wright, I. A. (2014). Impact of a coal mine waste discharge on water quality and aquatic ecosystems in the Blue Mountains World Heritage area. *Proceedings of the 7th Australian Stream Management Conference.* Townsville, Queensland, 385-391.

Belmer, N., Paciuszkiewicz, K., & Wright, I. A. (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.

Belmer, N., & Wright, I. A. (2020). The regulation and impact of eight Australian coal mine wastewater discharges on downstream river water quality: A regional comparison of active versus closed mines. *Water and Environment Journal*, *34* (3), 350–363.

Cohen, D. (2002). Best practice mine water management at a coal mine operation in the Blue Mountains. Masters of Engineering (Honours) Thesis, University of Western Sydney, Nepean.

NSW EPA Environment Protection License 726 for Clarence Colliery (2013 ver.) *Environment & Heritage | POEO Licenses, Application and Notice Detail*. (n.d.). https://apps.epa.nsw.gov.au/prpoeoapp/Detail.aspx?instid=726&id=1514358&option=notice&range=POEO%20licence&noticetype=

NSW EPA Environment Protection License 726 for Clarence Colliery (2020 ver.) *Environment & Heritage | POEO Licenses, Application and Notice Detail*. (n.d.). https://apps.epa.nsw.gov.au/prpoeoapp/ViewPOEOLicence.aspx?DOCID=178535&SYSUID=1&LICID=726

Fleming, C., Morrison, K., Robba, L., Reynolds, J., & Wright, I. A. (2021). 14-Month Water Quality Investigation of Coal Mine Discharge on Two Rivers in NSW, Australia: Implications for Environmental Regulation. *Water, Air, & Soil Pollution*, *232* (3), 90-111.

Giam, X., Olden, J. D., & Simberloff, D. (2018). Impact of coal mining on stream biodiversity in the US and its regulatory implications. *Nature Sustainability*, *1* (4), 176–183.

Graham, K., & Wright, I. A. (2012). The potential and reality of the environment protection licensing system in New South Wales: The case of water pollution. *Environmental and Planning Law Journal*, *29* (5), 359–372.

New South Wales Government. NSW Protection of the Environment Operations Act (1997). https://www.legislation.nsw.gov.au/view/html/inforce/current/act-1997-156.

New South Wales National Parks and Wildlife Service. (2001). *Blue Mountains National Park: Plan of management.* https://www.environment.nsw.gov.au/research-and-publications/publications-search/blue-mountains-national-park-plan-of-management

New South Wales, Department of Environment and Climate Change, New South Wales National Parks and Wildlife Service, Australia, & Department of the Environment, W., Heritage, and the Arts. (2009). *Greater Blue Mountains World Heritage Area: Strategic plan.* Dept. of Environment and Climate Change (N.S.W.). https://www.environment.nsw.gov.au/research-and-publications/publications-search/greater-blue-mountains-world-heritage-area-strategic-plan

National Parks and Wildlife Act 1974 No 80— Wild Rivers Act NSW Legislation. (n.d.). https://www.legislation.nsw.gov.au/view/html/inforce/current/act-1974-080

Pond, G. J., Passmore, M. E., Borsuk, F. A., Reynolds, L., & Rose, C. J. (2008). Downstream effects of mountaintop coal mining: Comparing biological conditions using family- and genus-level macroinvertebrate bioassessment tools. *Journal of the North American Benthological Society*, *27* (3), 717–737.

Tiwary, R. K. (2001). Environmental Impact of Coal Mining on Water Regime and Its Management. *Water, Air, and Soil Pollution*, *132* (1), 185–199.

Younger, P. L. (2004). Environmental impacts of coal mining and associated wastes: A geochemical perspective. *Geological Society, London, Special Publications*, *236* (1), 169–209.

Wright, I. A., Belmer, N., & Davies, P. J. (2017). Coal Mine Water Pollution and Ecological Impairment of One of Australia's Most 'Protected' High Conservation-Value Rivers. *Water, Air, & Soil Pollution*, *228* (3), 90–108.