

Coal mine 'dewatering' of saline wastewater into NSW streams and rivers: a growing headache for water pollution regulators

Ian A. Wright^{1,2}

¹ School of Natural Science, University of Western Sydney, Locked Bag 1797, South Penrith DC, 1797. i.wright@uws.edu.au

² Dr Ian A. Wright Environmental Consulting, iwright.consult@gmail.com

Key Points

- The ionic composition, pH and salinity of four freshwater streams were strongly modified by coal mine wastewater discharges.
- The nature and extent of the geochemical modification differed from location to location.
- It is very likely that the water chemistry effects of the coal mines discharges have important water pollution and ecological implications, particularly for algal diatom communities.
- The NSW environmental regulations for each mine in this study, termed *Environmental Protection Licenses*, failed to include discharge limits on salinity or any major anion or cations.

Abstract

Alteration to the ionic chemistry of a river or stream as a result of a land use activity, such as mining, would ordinarily be defined as pollution under most water protection legislation and therefore should be regulated. However, this is not always the case, particularly in NSW. This paper reports on water chemistry in the vicinity of four coal mines in NSW. Each mine caused elevated pH and salinity and also modified the geochemistry of downstream waters. In all cases there was a change to the relative concentration of major anions and cations. In this study most reference (upstream) waterways had an ionic composition dominated by sodium and chloride ions while most coal mine drainage discharges caused increased concentrations (and often dominance) of sulfate and bicarbonate and other ions, in downstream waters. Results are compared to the Gibbs (1970) model for world geochemistry of surface waters. I discuss the implications of my findings to aquatic ecosystems and to the current regulatory approach controlling NSW mine wastewater discharges. I conclude that the levels and types of salts discharged to waterways from the coal mines are inadequately regulated and may represent an emerging environmental pollution dilemma.

Keywords

Water chemistry, anions, cations, mine drainage, salt, contamination, geochemistry, legislation

Introduction

Gibbs (1970) identified three 'natural' mechanisms that control the world's surface freshwater ionic chemistry: atmospheric precipitation (often related to distance to the ocean), geology and the evaporation - crystallisation processes. Unnatural factors can also change surface water ionic chemistry. For example, Hart & McKelvie (1986) concluded that surface water chemistry was sometimes influenced by irrigation activities which contributed large quantities of saline groundwater. The research conducted for this paper sought to determine whether the disposal of coal mine wastewater modified the ionic water chemistry of streams of different sizes, climate and geology in the Sydney Basin. I also evaluated whether geochemical water quality attributes were reflected in the water pollution regulations (in NSW termed 'Environmental Protection Licenses'), that apply to each of the four mining operations under the *Protection of the Environment Operations Act* (1997) NSW.

Water sample collection and analysis

Field work was carried out on a single day, 19 August 2011, in the Blue Mountains area (85 to 140 km west of Sydney), and south-western Sydney (60 to 80 km south-west of Sydney). The study areas included two

waterways in the western Blue Mountains area, Dalpura Creek (DC) and Coxs River (CR), as well as Bargo River (BR) and Georges River (GR), south-west of Sydney (Figure 1). All waterways were flowing and flow conditions were typical of dry weather. In all cases flow conditions were very similar upstream and downstream of the coal mines. Dalpura Creek was the exception as the mine discharge provided the majority (c. 90%) of the flow below the mine. Dalpura Creek is affected by contaminated groundwater from a coal mine (Canyon Colliery, EPL 558) which closed 14 years prior to the study (Wright & Burgin, 2009a,b; Wright *et al.*, 2011). The Coxs River received mine drainage from the Invincible Colliery (EPL 1095); however, this discharge stopped 17 months previous to the sample collection (Coalpac, 2011). Sampling for the Coxs River was undertaken in its headwaters in Ben Bullen State Forest. Tahmoor Colliery (EPL 1389) disposes of mine waste water into the Bargo River and the West Cliff Colliery (EPL 2504) releases waste water into a small tributary (Brennans Creek) in the upper reaches of the Georges River.

Water samples for major anion and cation analysis were collected from flowing surface water (collected mid-stream) from each of the freshwater streams, above and below each of the four mines (Canyon, Invincible, Tahmoor and West Cliff Collieries). Triplicate samples (125 mL) of water were taken (over a five minute period) and were analysed at a commercial NATA (National Association of Testing Authorities) accredited laboratory for major anions (carbonate, bicarbonate, sulfate, chloride) and major cations (calcium, magnesium, potassium, sodium). In addition a Yeo-Kal 611 water quality meter (Sydney) measured electrical conductivity and pH during sample collection. Five readings were taken over three minutes once the meter had equilibrated. For data analysis, all data were grouped into upstream sites (above all mine discharges) and downstream sites (below all mine discharges). Student's *t*-test was used to test for differences between upstream and downstream sites. I also compared results of cations (bicarbonate and sodium) to the level of TDS, calculated using electrical conductivity data, using the model developed by Gibbs (1970).

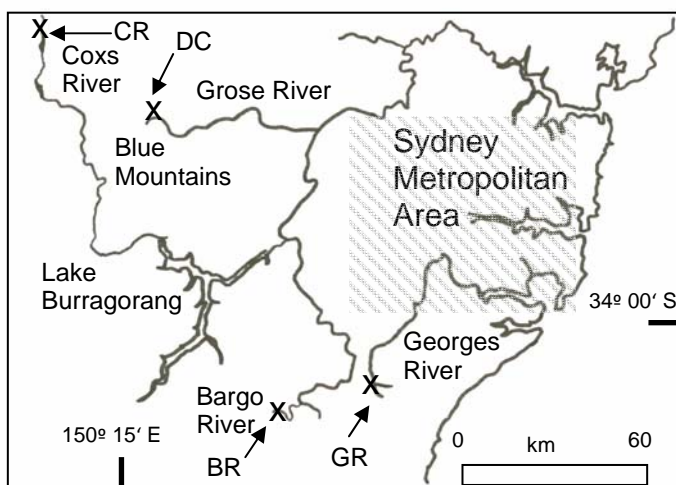


Figure 1. The Sydney Basin study area. The X symbol marks the approximate location of four coal mine discharges. Water samples were collected upstream and downstream of each discharge point. Two coal mines were in the Blue Mountains area (Coxs River (CR) and Dalpura Creek (DC), a very small tributary of the Grose River). The other mines were south-west of Sydney (Bargo River (BR), Georges River (GR)).

Results and discussion

Background reference water chemistry, upstream of mine discharges, varied according to the level of salinity (approximated using Electrical Conductivity (EC)) and pH. The two Blue Mountains waterways were both dilute with mean EC levels of 32 $\mu\text{S}/\text{cm}$ (Coxs River) and 35 $\mu\text{S}/\text{cm}$ (Dalpura Creek) above the mine discharges (Figure 2). EC levels were higher with mean levels of 176 $\mu\text{S}/\text{cm}$ and 253 $\mu\text{S}/\text{cm}$ in the upstream Georges River and Bargo River (Figure 2). The pH levels were both acidic in the Blue Mountains waterways (Dalpura Creek

and the Coks River) above the mine discharges (mean pH 5.4 and 6.3) (Figure 2). Levels of upstream pH were higher in south-western Sydney with mean pH of 6.7 in the Bargo River and 7.2 in the Georges River (Figure 2).

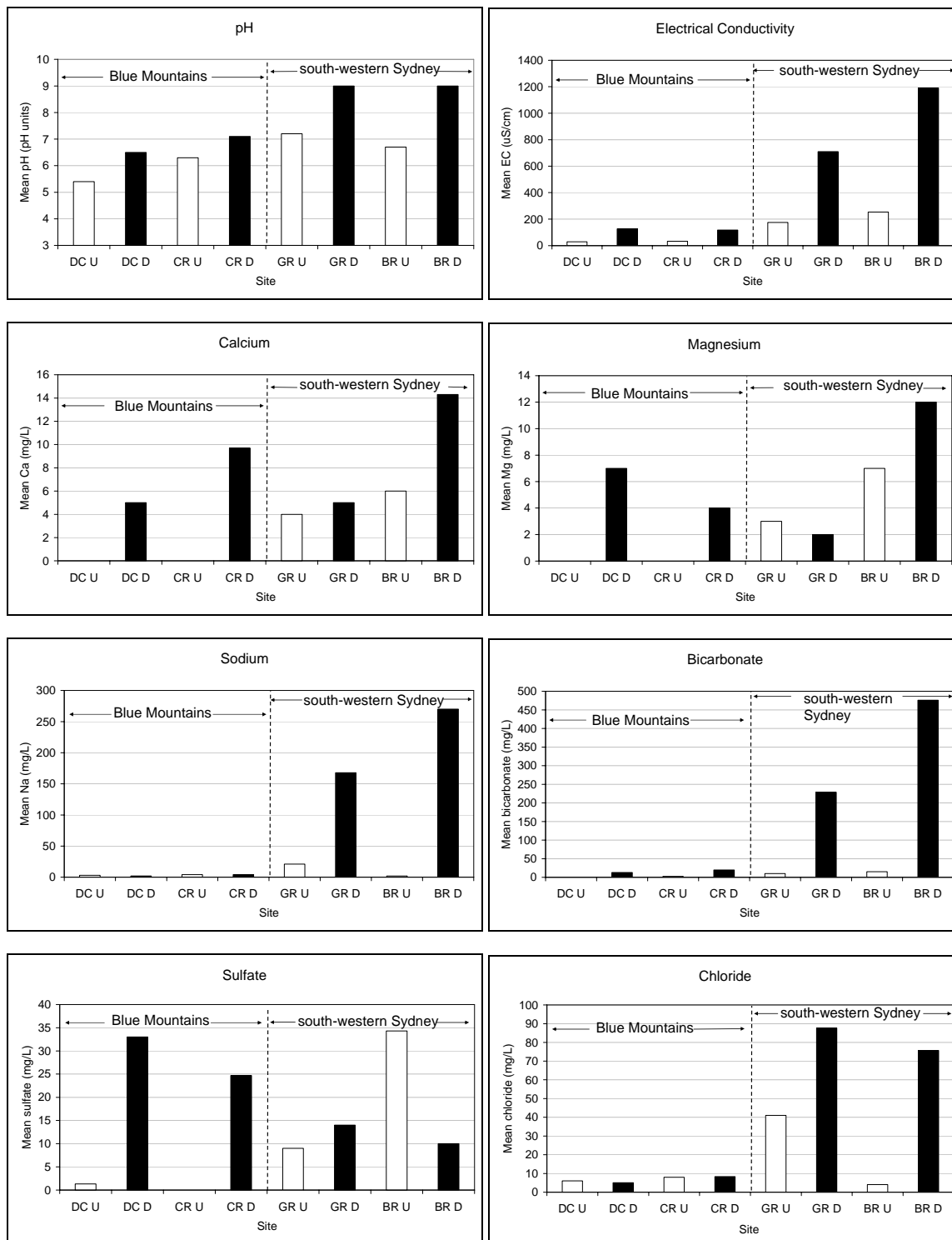


Figure 2. Mean water chemistry (EC and pH) and major ion concentrations in waterways upstream ('U' unshaded) and downstream ('D' black) of four coal mine wastewater discharges in two locations. Blue Mountains: Dalpura Creek (DC) and Coks River (CR). South-western Sydney: Georges River (GR) and Bargo River (BR) (See Figure 1 for locations).

Salinity (EC) rose significantly in all four waterways, below each mine discharge, by an average of 334% above the background (upstream) levels (Table 1). The smallest increase was Dalpura Creek (35 $\mu\text{S}/\text{cm}$ upstream to 126 $\mu\text{S}/\text{cm}$ downstream) and the largest was Bargo River (253 $\mu\text{S}/\text{cm}$ upstream to 1190 $\mu\text{S}/\text{cm}$ downstream (Figure 2). There was a highly significant increase in pH below all four mine discharge points with an average rise of 1.5 pH units (Table 1). The smallest increase was in Coxs River (0.8 pH units), then Dalpura Creek (1.1 pH units), Georges R (1.8 pH units) and the largest was Bargo River with a downstream increase of 2.3 pH units (Figure 1). Three of the four waterways were above pH 7.0 below each mine discharge point. Only Dalpura Creek remained acid (pH 6.5) below the mine. Both Bargo River and Georges River were strongly alkaline (pH 9.0) at sites downstream of the mine discharges (Figure 2).

All major ions, with the exception of chloride, were significantly higher below the mine discharge points compared to upstream (Table 1, Figure 2). The mean downstream ion concentration increased by a minimum of 48% (chloride) to a maximum of 687% (sodium), compared to upstream levels (Table 1). The geochemistry of all reference waterways (above mine discharges) in this study were dominated by sodium and chloride ions, according to their mean concentration in mg/L (Table 1; Figure 2). The sub-dominant anions and cations in the reference waterways varied from site to site (Table 1; Figure 2). Downstream of the mine discharges there were extensive changes to the ionic composition, relative to upstream, in all four waterways. Sodium remained the dominant cation downstream of the mine discharge in two waterways (Bargo River and Georges River). In the Blue Mountains calcium became the dominant downstream cation in the Coxs River and magnesium became dominant in Dalpura Creek below the mine. Although chloride was the dominant anion in all upstream sites, it was replaced by sulfate below the two mines in the Blue Mountains (Coxs R and Dalpura Ck). In the Georges and Bargo River bicarbonate became the dominant anion below both mine discharges (Figure 2). The differences are likely to be influenced by the local geology, distance to the ocean, and may also be influenced by the level and type of mining activity and water treatment at each location.

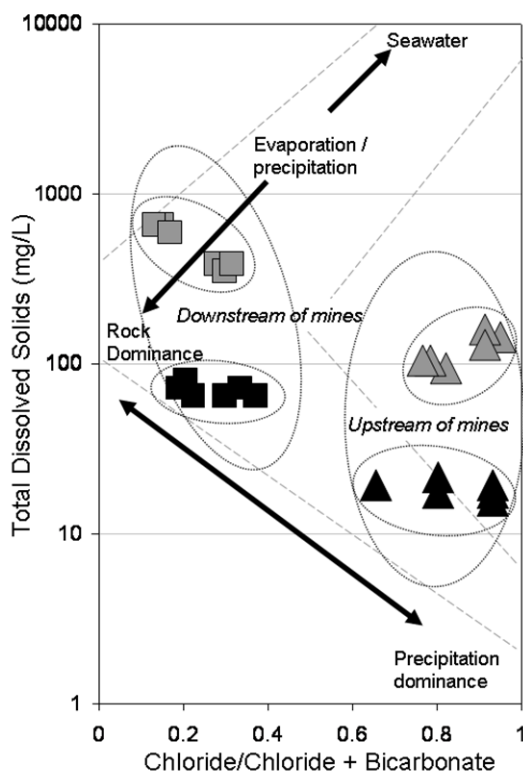


Figure 3. Gibbs (1970) Diagram and ionic balance upstream and downstream of the coal mines. Triangle symbols are upstream of mines and square symbols are downstream. Black symbols are from Blue Mountains and grey symbols are from south-western Sydney.

Results revealed that each of the coal mine discharges modified the stream ionic composition downstream of the discharge point. The extent and nature of the change differed from location to location. A limitation of this study is that the distance downstream of the water chemistry changes from the coal mines are not known. The upstream and downstream chloride and bicarbonate (and TDS) results were plotted on the model developed by Gibbs (1970) to represent the range of total dissolved salts across the world's range of surface freshwaters (Figure 3). The upstream and downstream samples were clustered separately. There were geographical differences with the Bargo and Georges River being more 'salty' (higher TDS) upstream and downstream of the mines. All downstream sites clustered closer to the centre-left of the Gibbs diagram, closer to 'rock dominance' zone in the Gibbs (1970) model (Figure 3). Thus water below the mines resembled the ionic composition of water found in 'rock dominated' geochemistry's according to the Gibbs model. This signals the nature and scale of ionic water quality impairment due to the mine waste water discharge.

Table 1. Water chemistry summary statistics (mean and standard error) for water samples collected at all sites upstream (U/S) and downstream (D/S) of four coal mine discharges on the August 2011 survey. The percentage increase and Student's *t*-test and probability results are given for differences between upstream and downstream. (p* < 0.05; ***p* < 0.001; ****p* < 0.0001, *ns* = not significant).**

Comparison	Water chemistry attribute									
	pH (ph units)	EC (μ s/cm)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	CO ₃ (mg/L)	HCO ₃ (mg/L)	SO ₄ (mg/L)	Cl (mg/L)
U/S mean (Std.Error)	6.42 (0.15)	123.6 (21.8)	2 (0.46)	2.5 (0.7)	14.1 (3.3)	1.05 (0.18)	not detected	46 (1.1)	4.1 (1.04)	29.8 (7.3)
D/S mean (Std.Error)	7.92 (0.25)	536.3 (102.7)	8.5 (1.2)	6.2 (1.1)	110.9 (34.3)	6.75 (0.2)	14.9 (6.5)	184.4 (57.1)	20.4 (2.7)	44.2 (11.4)
Difference	1.5	412.7	6.5	3.7	96.8	5.7	14.9	138.4	16.4	14.4
% increase above U/S	23	334	325	148	687	543	-	301	400	48
<i>t</i> value (<i>p</i>)	5.1 (***)	3.9 (**)	5.16 (**)	2.8 (*)	2.8 (*)	2.9 (*)	2.2 (*)	3.15 (**)	5.6 (***)	1.1 (ns)

The ecological implications of such modified water chemistry are unknown for each of the waterways. An earlier study detected toxic levels of zinc in Dalpura Creek and impaired macroinvertebrate communities further downstream in the Grose River (Wright & Burgin, 2009a,b). It is possible that other toxicants were present in the mine discharges that were not assessed in this study. The pH, ionic and salinity changes in water chemistry revealed in this study are likely to have adverse consequences for aquatic ecosystems. For example, the EC and pH in the Georges River and Bargo River exceeded the ANZECC (2000) water quality 'trigger levels' for ecosystem protection. Algal diatom communities in the United States (Potopova and Charles, 2003) were modified according to variations in ionic composition. Changes to the concentration of each anion and cation, along with changes in EC and pH, as recorded in this study, were all found to strongly affect United States diatom species composition (Potopova & Charles, 2003). Other adverse ecological consequences may occur higher in the food web when mine-related geochemical changes modify algal communities at the base of aquatic food chains. The synergistic effects of toxic contaminants (such as zinc) from the mine drainage may combine with the ionic changes to have multiple ecological impacts.

Waste water discharge limits for each of the four coal mines in this study are presented in Table 2. None of the four NSW *Environmental Protection Licences* include any wastewater discharge limits on salinity (EC) or major anions or cations (Table 2). It is not known if any risk assessment (e.g. ANZECC, 2000) was conducted to determine the various discharge variables and respective limits. It is noteworthy that two of the discharges in this study have ceased operation. The Canyon Coal Mine (EPL 558) ceased mining in 1997 and the licence has been surrendered but mine drainage from the mine continues to flow into Dalpura Ck, due to groundwater

inflow. No environmental remediation has been undertaken on the water pollution that continues to be discharged from this mine into Dalpura Ck and the Grose River (Wright *et al.*, 2011). The borehole discharge from Invincible Colliery into a tributary of Coxs R (EPL 1095) last operated in March 2010 (17 months prior to this study) and the infrastructure has been removed (Coalpac, 2011). Unpublished data indicates that EC levels were much higher below this discharge during its operation. The fact that such pollution remains measurable 17 months after the last operation is evidence of the long-term residual pollution of ionic water pollution from these two coal mines.

Conclusion

Wastewater discharges from four coal mines caused significant changes to water geochemistry in four freshwater streams and rivers in the Hawkesbury-Nepean catchment and the Sydney Basin. The water chemistry modifications, downstream from each mine, were different. However, there were three common trends; downstream water was more saline, had higher pH, and had strongly modified ionic composition. These results indicate that the discharge of waste water from each coal mine could be considered as water pollution (as defined in the *Protection of the Environment Operations Act*, 1997 (NSW)), notwithstanding an examination of the pollution licence public register (NSW OEH, 2011) indicating that there are currently (September 2011) pollution licenses for 69 coal mines issued in NSW. Further, the change in water chemistry may constitute a 'key threatening process', as defined in the NSW Threatened Species Conservation Act, 1995 (NSW), as this can cause considerable stress to downstream aquatic ecosystems of high conservation value. The regulation of the discharges from each mine (Table 2) currently fails to impose any discharge limits on wastewater salinity or on any major anion or cation. This area of regulation requires further examination. Similarly, there is a need for further research to provide evidence for regulatory authorities on the direct and cumulative impacts of changes in water chemistry on ecosystem health, particularly for waterways of high conservation value.

Table 2. Coal mine wastewater discharge conditions under *Protection of the Environment Operations Act* (1997) NSW, as specified in the following 'Environmental Protection License' (EPL) 100 % discharge limits.

	EPL 558	EPL 1095	EPL 1389	EPL 2504
Discharges to	Dalpura Ck	Trib. Of Coxs R	Bargo R	Brennans Ck (trib. of Georges R)
Is coal mine active?	No	Yes, but the discharge point ceased operation in March 2010	Yes	Yes
Oil & Grease (mg/L)	10	10	10	10
pH (pH units)	-	6.5-8.5	6.5-9.0	6.5-9.0
Total Suspended Solids (mg/L)	-	30	30	50
Iron (mg/L)	1	-	-	-
Zinc (mg/L)	5	-	-	-

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