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Urban Geochemical Contamination of High Conservation Value Upland Swamps, Blue Mountains Australia

Nakia Belmer · Ian A Wright · Carl Tippler

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Abstract Upland swamps of the Blue Mountains are unique and legislatively protected peat swamp communities. This study investigated water chemistry of surface waters from seven Blue Mountains Upland Swamps (BMUS), four within urbanised catchments and three from naturally vegetated catchments. The purpose of the study was to investigate any ionic contamination from urban development. Water chemistry of non-urban BMUS was acidic (mean pH 4.7) and dilute (mean EC 26.6 μS/cm) and dominated by sodium and chloride ions with most other major ions at low concentrations, often below detection limits. In contrast, urban BMUS had higher pH (mean 6.6) and salinity (mean 153.9 μS/cm) and were dominated by calcium and bicarbonate ions. The results of this study support the hypothesis that urban concrete contamination is modifying the geochemistry of urban BMUS. Further research is required to investigate ecological implications of the contamination and also to explore measures to protect such sensitive wetlands of high conservation value from urban development.

N. Belmer (✉) · I. A. Wright
School of Science and Health, University of Western Sydney, Locked Bag 1797, South Penrith DC 1797 NSW, Australia
e-mail: 17255859@student.uws.edu.au

C. Tippler
Department of Environment and Geography, Macquarie University, Sydney, NSW, Australia

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1 Introduction

Blue Mountains Upland Swamps (BMUS) are unique plant communities which are generally found at altitudes of 500 to 1000 m in the Blue Mountains area of SE Australia (OEH 2013; Commonwealth of Australia 2014). BMUS have legislative protection as endangered ecological communities at both state and national levels, with a total of less than 2000 ha in existence (NSW OEH Office of Environment and Heritage 2013; DoE Department of the Environment 2005; BMCC Blue Mountains City Council 2013). Although much of the area is protected as part of the Greater Blue Mountains World Heritage area, urbanisation of BMUS catchments has adversely affected their biophysical condition (BMCC 2014). Urban development has modified natural flow regimes and has triggered accelerated erosion, channelisation and sedimentation of urban BMUS communities (New South Wales Scientific Committee 2007; Fryirs et al. 2012, 2014). The 'Urban Stream Syndrome' is a term coined by Paul and Meyer (2001) to describe the multiple impacts of urbanised catchments on stream hydrology, water quality and ecological condition (Walsh et al. 2005). BMUS in urban areas are often degraded by weed invasion, consistent with the urban stream syndrome (New South Wales Scientific Committee 2007).

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This study investigated the water chemistry of surface waters in BMUS in urban and non-urban catchments. This is considered urgent as very little information is available on typical water chemistry of natural BMUS or those within urban catchments and urban development in the area is rapidly expanding. Typically, the new urban development in the Blue Mountains makes extensive use of concrete stormwater infrastructure, such as road gutters, stormwater pipes and drainage canals. Recent studies suggest that concrete stormwater infrastructure modifies urban stream geochemistry, particularly in areas that naturally have acidic and dilute water chemistry (Davies et al. 2010; Wright et al. 2011; Tippler et al. 2014). The purpose of this study was to investigate background geochemistry of BMUS surface waters in natural and unmodified catchments compared to those in urban catchments. This was sought, in particular, to detect any ionic impairment that may be attributed to dissolution of concrete materials (e.g. high pH, elevated potassium, calcium and bicarbonate concentrations). This is part of a broader study which is also collecting BMUS macroinvertebrates to assess whether urban BMUS have ecosystems and geochemistry degraded in a manner consistent with the 'urban stream syndrome'.

2 Methods

This study was conducted at seven BMUS (Table 1) with four located in urbanised catchments and three in non-urban naturally vegetated catchments. The degree of urbanisation within each BMUS catchment was classified by measuring the percentage of directly connected impervious surfaces (% IS). This was achieved through the Sutherland (2000) method by using percentage total impervious area which was derived through calculating impervious surfaces in BMUS catchments from GIS mapping. Other catchment details were calculated including percentage of BMUS catchment covered by impervious road surfaces (generally bitumen) and the percentage of highway road surfaces. The major arterial road 'Great Western Highway' lies within part of three urban BMUS catchments in this study.

Water quality data was collected from all BMUS on six occasions and from two BMUS (one urban and one non-urban) on seven additional occasions between June 2014 and June 2015. On each sampling occasion, five in situ replicate water quality measurements were

Table 1 Location, names and physical details of each BMUS and catchment sampled in this study, including those in naturally vegetated non-urban catchments (Reference) and urban catchments (Urban). Proportion of BMUS catchment covered by impervious surfaces is given (% impervious area; % directly connected impervious area) and have been calculated using the Sutherland method (Sutherland 2000). Proportion of catchment covered by impervious road surfaces, highway surfaces and natural vegetation is also provided

Swamp name	Longitude and latitude	Elevation (m ASL)	Swamp area (ha)	Catchment area (ha)	Impervious area (ha)	% of catchment covered by impervious surface	% of catchment covered by directly connectedimpervious surface	% of catchment impervious road surface	% of catchment highway surface	% of catchment natural vegetation
Newnes Plateau Swamp 'NP' (Reference)	Lat 33.435377, Long 150.22046	1070	14.6	133.8	0	0	0	0	0	100
Mt Hay Swamp 'MH' (Reference)	Lat 33.668644, Long 150.346508	920	3.9	65.3	0	0	0	0	0	100
Hat Hill Swamp 'HH' (Reference)	Lat 33.599941, Long 150.328782	967	4.1	35.5	0	0	0	0	0	100
Marmion Road Swamp 'MAR' (Urban)	Lat 33.696033, Long 150.325188	942	5.1	51.2	10.8	21.1	2.8	6.6	2.6	46.9
North Lawson Swamp 'NL' (Urban)	Lat 33.719991, Long 150.424565	695	1.1	69.2	9.8	10.2	2.1	7.4	3.1	41.4
Bullaburra Swamp 'BUL' (Urban)	Lat 33.727319, Long 150.412928	755	0.8	21.1	5.76	27.3	21.2	17.3	11.4	9.8
Loftus Street Katoomba Swamp 'KAT' (Urban)	Lat 33.718096, Long 150.30495	962	6.1	106.3	29.1	27.3	11.1	8.4	0	20.6

collected from flowing surface waters using a calibrated TPS AQUA-Cond-pH meter for pH, electrical conductivity and a calibrated YSI ProODO meter for turbidity, temperature and dissolved oxygen. Duplicate grab samples in clean and unused bottles were collected for analysis of major anions and cations at a commercial water testing laboratory.

Student's *t* test was used to determine if mean water quality results varied significantly between urban and non-urban BMUS.

3 Results

Water chemistry contrasted sharply between the urban and non-urban locations with most variables significantly higher at urban BMUS (Table 2). Water from non-urban BMUS was more acidic (mean pH 4.7) when compared to urban swamps (mean pH 6.6). Salinity of the urban BMUS (mean 153.9 μS/cm) was more than 5.5 times higher than non-urban BMUS (Table 2). Non-urban BMUS were dominated by sodium and chloride ions with most other ionic attributes at low concentrations, often below detection limits (Table 2; Figs. 1 and 2). In contrast, urban BMUS were dominated by calcium and bicarbonate ions (Table 2; Figs. 1 and 2). One urban swamp in particular (Bullaburra) had the highest mean levels of bicarbonate (50.7 mg/L), sulfate (73.7 mg/L), potassium (7.9 mg/L) and calcium (34 mg/L) when compared to all other BMUS (Figs. 1 and 2). The catchment of this urban BMUS had the lowest proportion of native vegetation. It also had the highest proportion of impervious surfaces, roads and highway.

4 Discussion

This study reveals that water chemistry of urban BMUS differed markedly to non-urban BMUS. Non-urban swamps were acidic (pH <5.4), had low salinity (<41 μS/cm) and were dominated by sodium and chloride ions. These results are similar to streams in naturally vegetated non-urban catchments in the nearby Sydney basin, although BMUS are more acidic and with lower salinity (Wright et al. 2011; Tippler et al. 2012). The geochemistry of urban BMUS showed strong similarities to urban streams in the Sydney basin which have been shown to have elevated calcium, potassium and bicarbonate ions (Davies et al. 2010; Wright et al. 2011; Tippler et al. 2014).

Of all the urban BMUS, the swamp at Bullaburra recorded the highest bicarbonate, potassium and calcium levels (Figs. 1 and 2). Its catchment did have the

Table 2 Summary statistics for water chemistry results collected from four urban and three non-urban BMUS (collected June 2014 to June 2015)

Source of variation (units of measurement)	*t* stat	*p* value	Non-urban BMUS		Urban BMUS	
			Range	Mean	Range	Mean
pH (pH units)	34.9	(<0.0001)	4.2–5.4	4.7	5.8–9.2	6.6
Conductivity (μS/cm)	15.5	(<0.0001)	20–41	26.6	44.6–471.8	153.9
Dissolved oxygen (% saturation)	1.8	(0.067)	56.7–93.6	71.9	12.1–102.6	69.1
Turbidity (NTU)	7.1	(<0.0001)	0.2–3.0	1.4	0.7–22.8	3.8
Temperature (°C)	6.1	(<0.0001)	3.2–16.5	10.2	6.6–21.5	12.9
Bicarbonate (mg/L)	6.6	(<0.0001)	BD–7	1.0	BD–56	24.7
Sulfate (mg/L)	2.6	(0.017)	BD–1	<0.5	BD–140	20.5
Calcium (mg/L)	4.0	(0.0005)	BD–0.6	<0.5	1.2–63	14.2
Magnesium (mg/L)	7.0	(<0.0001)	BD–0.6	<0.5	BD–2.2	1.0
Sodium (mg/L)	4.7	(<0.0001)	2.6–5.4	3.7	3–24	9.1
Potassium (mg/L)	4.1	(0.0005)	BD–0.5	<0.5	BD–12	2.9
Chloride (mg/L)	5.3	(<0.0001)	3–7	5.3	4–26	11.7

BD below laboratory detection limits

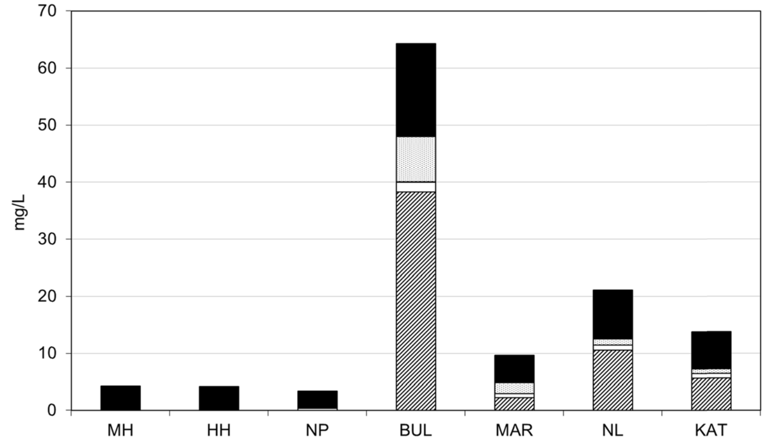

Fig. 1 Mean concentration (mg/L) of major cations in the surface waters at each of seven BMUS in the Blue Mountains sampled from June 2014 to June 2015. Sodium is *black*, potassium is *dotted*, magnesium is *unshaded* and calcium is *cross-hatched*. The first three are naturally vegetated reference (MH, HH and NP), and the next four are urban (BUL, MAR, NL and KAT). Swamp location and catchment details are given in Table 1

equal greatest impervious surface coverage (27.3 %), and it did have the highest proportion of 'directly connected' impervious surfaces (17.3 %) (Table 1). Such impervious levels are typical of 'urban' catchments (Tippler et al. 2014). This swamp also had the highest proportion of its catchment covered by highway (Table 1). We suggest that the higher calcium and bicarbonate levels in this BMUS are linked to recent highway construction in this catchment with associated installations of new concrete stormwater infrastructure which capture and direct highway runoff to the head of the BMUS. Further investigation should be undertaken to clarify this major source of contamination.

The pattern of geochemical contamination (elevated calcium, bicarbonate, potassium, EC and pH) in urban BMUS supports the hypothesis that urban concrete contamination (Davies et al. 2010; Wright et al. 2011; Tippler et al. 2014) is modifying the geochemistry of these naturally acidic, dilute wetlands. The implications of such geochemical modification of BMUS is uncertain, but it is clear that BMUS within urban catchments have a strongly modified water chemistry that is unnatural and is likely to be a potential source of stress to BMUS ecosystems. Further investigation is currently underway to explore whether these findings are associated with degradation of BMUS ecosystems. Given the conservation significance of BMUS and the continuing urban development in the Blue Mountains region, it is recommended that further investigation is required to explore potential sources of human disturbance to BMUS. Further investigation is required to explore how urban development and healthy BMUS can sustainably coexist in a manner that protects their unique environmental values. Consideration also needs to be given to alternative materials, or treatments (e.g. Grella et al 2014), that could be applied to concrete stormwater infrastructure to reduce the dissolution of concrete in such ecologically sensitive locations.

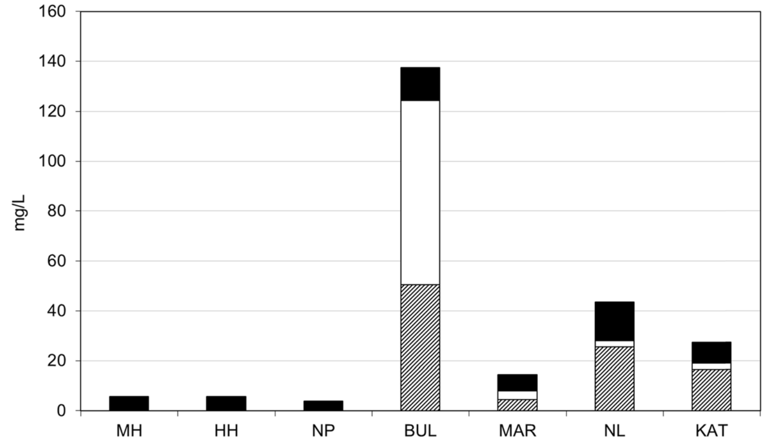

Fig. 2 Mean concentration (mg/L) of major anions in the surface waters at each of seven BMUS in the Blue Mountains sampled from June 2014 to June 2015. Chloride is *black*, sulfate is *unshaded* and bicarbonate is *cross-hatched*. The first three are naturally vegetated reference (MH, HH and NP), and the next four are urban (BUL, MAR, NL and KAT). Swamp location and catchment details are given in Table 1

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