Impact of concrete on riparian ecosystems

K Purdy and I A Wright
School of Science and Health, Western Sydney University, Richmond, NSW 2753, Australia
E-mail: k.purdy2@westernsydney.edu.au

Abstract. Throughout the world, concrete is used extensively in urban development. Due to its convenience and durability, most paths, car parks, dams, and even drainage systems are constructed from concrete. However, recent studies indicate that concrete significantly affects water chemistry and that concrete infrastructure may have a major effect on the chemistry of nearby streams. This is particularly relevant for sensitive waterways such as those in the Blue Mountains region in Sydney, Australia. This study aimed to investigate the chemical changes associated with concrete exposure by conducting water recirculation experiments. Water collected from a pristine Blue Mountains Upland Swamp (BMUS) was mildly acidic (average pH of 4.65) with a low electrical conductivity (EC of 57.99μS/cm) before concrete exposure. After the water was continuously recirculated through a concrete pipe for 120 minutes, pH and EC increased significantly, to 7.87 and 137.72μS/cm respectively. Significant increases in concentrations of ions such as bicarbonate, calcium and sulphate were also observed. Results verify previous findings that concrete significantly and rapidly affects water chemistry and support the hypothesis that concrete plays a significant role in the chemical differences seen between urban and non-urban waterways. Results also indicate that concrete is a source of metals such as copper, chromium, strontium, titanium, and lithium. Furthermore, this study aimed to investigate whether these metals have the potential to affect ecosystems more broadly. Salix babylonica, a common invasive plant species in the Sydney region, was grown in pristine BMUS water and concrete-recirculated BMUS water. Plants grown in concrete-recirculated water had significantly greater new growth and the tissue of these plants was significantly higher in concentrations of barium, copper, lead, manganese, and strontium. As metals in the water appear to be moving into plant tissue, results suggest that these metals are bioavailable and thus have the potential to move into higher trophic levels and the ecosystem more generally. Further investigation is required to determine how far these metals may permeate the food chain.

1. Introduction
On a worldwide scale, urbanisation is increasing and has a major effect on stream health in what is known as “urban stream syndrome”. Urban development is associated with a large increase in the proportion of the stream catchment covered by impervious surfaces such as roads, drains and roofs [1]. This altered hydrology can have a range of effects, including reduced groundwater, increased erosion of streambeds and surrounding areas, and loss of small streams [2,3]. Additionally, waterways in catchment areas with higher proportions of urban surfaces are associated with specific chemical characteristics, including higher pH, higher electrical conductivity (EC), and higher concentrations of nutrients and ions [4-7]. Recent studies [7-11] indicate that concrete infrastructure may significantly affect nearby streams.
and thus play a major role in this consistent pattern of urban stream degradation. As concrete is used widely in urban construction and in the drainage network, any water flowing into urban streams has significant contact with concrete surfaces\textsuperscript{[11]}. Concrete is highly reactive and is constantly being degraded\textsuperscript{[9]}. As water runs over a concrete surface, a series of chemical reactions takes place, including decalcification, dissolution, carbonation, and leaking of cement components\textsuperscript{[12]}. Thus, leaching of concrete materials into water occurs. Previous studies\textsuperscript{[9,13-15]} have observed that concrete exposure results in increases in water pH and electrical conductivity (EC), as well as increases in concentrations of calcium, bicarbonate, and other ions. Additionally, Davies \textit{et al}\textsuperscript{[11]} noted that, after contact with concrete, rainwater and non-urban stream samples became more like the sampled urban streams in terms of chemical composition.

Investigation into the effects that concrete may have on nearby streams is particularly important in fragile ecosystems such as Blue Mountains Upland Swamps (BMUS). BMUS are unique ecological communities, occupying a total area of less than 2000 hectares in the Blue Mountains area of southeastern Australia\textsuperscript{[16]}. They are home to a number of endangered plant and animal species\textsuperscript{[17]} and are extremely important ecologically. Despite being located in a World Heritage area and having legislative protection under the Threatened Species Conservation Act and Commonwealth legislation\textsuperscript{[18]}, urbanisation of the Blue Mountains region has negatively affected many swamps\textsuperscript{[16]}. Effects include degraded water health, erosion, desiccation, and weed invasion\textsuperscript{[17]}. BMUS are particularly fragile and susceptible to the negative effects of urbanisation as their natural water is acidic and dilute with a low buffering capacity\textsuperscript{[9]}. Because of the essential ecosystem services of the swamps, their immense natural value, and their fragile water chemistry, it is vital to assess the impact that concrete infrastructure is likely to have on these fragile, high-conservation communities.

This study aimed to:
- Verify the pH and EC changes previously seen in concrete-circulated water
- Investigate how concrete changes water ion and metal concentrations
- Determine whether these changed ion and metal concentrations in water are bioavailable and are transported into plant tissue
- Determine any effect that concrete exposed water may have on the growth of an invasive species

2. Materials and methods

2.1. Water collection and recirculation
Thirty litres of water were collected from the ‘Kings Tableland’ BMUS (-33.763255, 150.383623). This is considered a pristine BMUS as it has a predominantly non-urban catchment. Water was collected in plastic containers, previously rinsed with deionised water, and rinsed three times with swamp water to ensure that there was no contamination. Samples were collected with minimal headspace in the container to limit gas exchange between the water and air. The water was collected from a small outlet stream in the lower margins of the swamp. Water was collected on 1/10/2018 and 10/10/2018.

The water was continuously circulated through a steel-reinforced, concrete stormwater pipe (length 2500 mm, diameter 225 mm) placed on a frame with a grade of 2.7\%. 9 L of water was used per experimental run. Following the methods of Davies \textit{et al}\textsuperscript{[11]}, the water was pumped through the concrete pipe using a 240-volt submersible electric water pump from a plastic sump placed at one end (figure 1). The water travelled through a vinyl tube into the opposite end of the concrete pipe, where it flowed back through the pipe into the sump. The vinyl tube was clamped so that water was delivered 300 mm inside the pipe, to avoid backflow and subsequent water loss, giving a total contact length of 2200 mm. The water flow was approximately 100 mm in width. The flow rate generated by the pump was 0.44 L/s, calculated as the time taken to fill a 10 L bucket averaged over three replicates.
Figure 1. The experimental layout for the water recirculation.

pH (pH units), electrical conductivity (µS/cm), and temperature (°C) readings were initially taken every three minutes for approximately 50 minutes of the experimental period and at 10-minute intervals for the rest of the period using a handheld meter with the probes placed in the sump (TPS Aqua-C waterproof conductivity-TDS-temperature meter). A data-logging water probe (HYDROLAB DS5, serial number 62044) was also placed in the sump and used as a secondary monitor with readings being taken every 30 seconds. Water quality was monitored with both the probe and the meter for five minutes prior to starting the water circulation to allow the readings to stabilise and to establish baseline values.

The water was recirculated for a period of 120 minutes. Three approximately 200 mL samples were taken at the beginning of the experiment and another three were taken at the end of the experiment. These ‘before’ and ‘after’ samples were sent to a commercial, quality-accredited laboratory to determine major ion and metal concentrations. The experiment was repeated three times with the above methods to provide experimental replicates.

Prior to recirculation experiments and in between replicates, the pipe, pump and tubing were rinsed using distilled water. In between replicates, the pipe was also rotated to ensure that the water was not contaminated by previous trials. All three trials were conducted over the course of one day (12/10/2018).

2.2. Plant growth
Branches of an invasive willow species (*Salix babylonica*) were collected from a single tree on the bank of South Creek in Windsor Downs, NSW (-33.68, 150.81). This species was chosen as it is fast growing and is easy to grow in laboratory conditions. Additionally, it is a problematic weed species in BMUS communities and the wider Sydney region [18].

Willow branches were placed in two water treatments: unmodified pristine BMUS water, collected from the Kings Tableland BMUS, and swamp water that had been recirculated in a concrete pipe, as described previously. Branches were trimmed to approximately 30 cm cuttings and were stripped of all leaves and shoots. They were then placed individually in plastic 500 mL beakers, which were filled with 400 mL of the respective water treatment and covered with plastic wrap to minimise evaporation, with a small hole left for the cutting. Branch collection and placement occurred on a single day.

The plants were randomly assigned positions in a growth room, where they were exposed to 24-hour UV light and approximately constant temperature. Mild temperature fluctuations from 20-24°C occurred throughout the growth period, measured with a maximum-minimum thermometer. Beakers were topped up to 400 mL with deionised water on a weekly basis.

2.3. Harvest and analysis
The plants were harvested on the 09/01/2019, after seven weeks of growth. For each plant, maximum shoot and root length, stem height, the length of five random leaves, and whole plant wet weight were measured. Plants were then dried in an incubator (Labec incubator S4218) for 9 days at 38 degrees
Celsius. The dry weight of the plants was then recorded and whole plant weight, trunk only, and root, shoot and leaf combined weights were recorded. Within each treatment group, plants were randomly sorted into six subgroups, acting as six replicates of plant tissue. The five plants in each subgroup were then ground to a fine powder using a ceramic mortar and pestle. The powder was sieved with an 850-micron sieve. Samples were then sent to a NATA accredited commercial laboratory for analysis of major metals.

2.4. Statistical analyses
All statistical analyses and graphs were produced using Microsoft Excel. Differences in growth parameters and in metal concentrations in tissue across the two water treatments were evaluated using a Student’s t-test assuming unequal variance. P-values less than 0.05 were considered significant.

3. Results

3.1. Water recirculation

![Figure 2](image-url)  
**Figure 2.** Average changes in pH (a) and electrical conductivity (b) of BMUS water over time when continuously circulated through the concrete pipe for 120 minutes, calculated over three replicate runs.

Across all three recirculation trials, pH increased significantly over the 120-minute recirculation period (figure 2). Pristine BMUS water was mildly acidic before recirculation, with an average pH of
4.66. This increased to a mean pH of 7.87 after circulation \((p=0.00043)\). EC also increased significantly over the recirculation period (figure 2). Pristine BMUS water began with an average EC of 57.99 \(\mu\)S/cm. EC rose steadily and approximately linearly over the 120 minutes, and the water had an average final EC of 137.72\(\mu\)S/cm \((p=0.0034)\).

Significant increases in certain metal concentrations were observed after recirculation (table 1). Chromium, titanium, and lithium rose from undetectable concentration levels (less than 1 \(\mu\)g/L) to average concentrations of 12.33, 2.17 and 2.67 \(\mu\)g/L, respectively. Copper results varied, however increases were also observed across all three runs. Potassium increased from undetectable levels (<0.5 mg/L) to an average of 7.43 mg/L and bicarbonate concentrations increased from undetectable (<5 mg/L) to an average of 42.33 mg/L. Increases were observed in strontium, chromium, titanium, lithium, calcium, sulphate, potassium and bicarbonate concentrations.

### Table 1. Major metal and ion chemistry increases for pristine BMUS water before and after concrete circulation. All means are calculated as the average of the measured concentrations across three replicate samples and \(p\)-values are according to paired t-tests conducted on the before and after values for the three replicate runs. Significant \(p\)-values (<0.05) are presented in red.

| Metal/ion (units) | Mean before | Mean after | Significance of change \((p\) value) |
|-------------------|-------------|------------|-------------------------------------|
| Sodium (µg/L)     | 6.56        | 7.01       | 0.059                               |
| Chloride (µg/L)   | 9.22        | 9.78       | 0.10                                |
| Strontium (µg/L)  | 7.41        | 29.22      | 0.0032                              |
| Chromium (µg/L)   | <1          | 12.33      | 0.044                               |
| Copper (µg/L)     | 3.67        | 13.44      | 0.096                               |
| Titanium (µg/L)   | <1          | 2.17       | 0.0083                              |
| Lithium (µg/L)    | <1          | 2.67       | 0.037                               |
| Calcium (mg/L)    | 1.40        | 14.78      | 0.00056                             |
| Magnesium (mg/L)  | 0.81        | 0.81       | 0.50                                |
| Sulphate (mg/L)   | 5.22        | 8.22       | 0.014                               |
| Potassium (mg/L)  | <0.5        | 7.43       | 0.016                               |
| Bicarbonate alkalinity (mg/L) | <5 | 42.33 | 0.0010 |

3.2. Plant growth

### Table 2. Growth measurements of plants grown in pristine BMUS water and concrete-recirculated BMUS water with significance of difference \((p\)-value) presented. Significant \(p\)-values are presented in red.

| Growth measurement (units) | Average of plants grown in pristine BMUS water | Average of plants grown in concrete-recirculated BMUS water | Significance of difference \((p\)-value) |
|----------------------------|-----------------------------------------------|----------------------------------------------------------|---------------------------------------|
| Maximum shoot length (cm)  | 10.83                                         | 15.75                                                    | 0.0018                                |
| Maximum root length (cm)   | 14.88                                         | 22.30                                                    | 0.0000000014                          |
| Leaf length (cm)            | 3.91                                          | 4.72                                                     | 0.0017                                |
| Whole wet weight (g)        | 12.21                                         | 13.13                                                    | 0.61                                  |
| Whole dry weight (g)        | 4.57                                          | 5.07                                                     | 0.53                                  |
| Dry weight excluding trunk (g) | 0.42                                        | 0.62                                                     | 0.0065                                |

Plants grown in concrete-recirculated water had significantly longer maximum root and shoot lengths and greater average leaf lengths (table 2). Differences in whole plant dry weight were not significant,
however, differences in dry weight of new growth (all plant matter excluding the trunk) were significant, with an average of 0.62 g for plants grown in concrete-recirculated water and 0.42 g for plants grown in pristine BMUS water.

3.3. Plant metal uptake

Plant tissue was tested for twenty different metals: arsenic, boron, barium, beryllium, cadmium, chromium, copper, cobalt, mercury, manganese, molybdenum, nickel, lead, antimony, selenium, tin, zinc, aluminium, lithium, and strontium. Significant differences in tissue concentrations between the two water treatments were observed across seven metals, namely barium, copper, manganese, lead, zinc, aluminium, and strontium (table 3). Higher concentrations of all of these metals except zinc and aluminium were observed in the plants grown in recirculated swamp water.

Table 3. Average concentration of selected metals in plant tissue grown in pristine and concrete-recirculated BMUS water. Growth measurements are given to 2 decimal places, while p-values are given to 2 significant figures.

| Metal     | Average concentration of plant tissue grown in pristine BMUS water (mg/kg) | Average concentration of plant tissue grown in concrete recirculated BMUS water (mg/kg) | Significance of difference (p-value) |
|-----------|---------------------------------------------------------------------------|----------------------------------------------------------------------------------------|-------------------------------------|
| Barium    | 19.33                                                                     | 27.08                                                                                  | 0.00026                             |
| Copper    | 11.67                                                                     | 14.50                                                                                  | 0.0050                              |
| Manganese | 72.83                                                                     | 92.92                                                                                  | 0.0012                              |
| Lead      | 2.33                                                                      | 6.50                                                                                   | 0.0038                              |
| Zinc      | 62.33                                                                     | 54.00                                                                                  | 0.022                               |
| Aluminium | 97.67                                                                     | 40.50                                                                                  | 0.000014                            |
| Strontium | 32.17                                                                     | 48.75                                                                                  | 0.000064                            |

4. Discussion and conclusions

Results of this study support previous work indicating that concrete rapidly and significantly affects water pH and EC. Elevated pH and EC values, as well as higher ionic concentrations for potassium, bicarbonate and calcium, are commonly associated with urbanised catchments [1,6,7]. As the concrete used in this experiment appears to cause a similar pattern of chemical differences to those seen in urban waterways, it seems highly likely that concrete in the urban landscape is playing a key role in the degradation of urban waterways.

Results also indicate that concrete is a substantial and unrecognised source of metal contamination, including copper, chromium, strontium, titanium and lithium. The presence of these metals in concrete is potentially due to the use of fly-ash in concrete to increase strength and durability [19]. Furthermore, results indicate that metals released by concrete are bioavailable and can be transferred into plant tissue. The presence of these metals is likely to have ecological and human impacts. While many heavy metals are important in plant and animal biochemical and physiological functions, they can also be toxic at higher concentrations [20]. For example, chromium toxicity in plants has been reported [21], and copper is very toxic to aquatic invertebrates [20]. Heavy metals can also have a range of effects on plant growth [22] and can affect a variety of processes, including tissue development, germination, and photosynthesis [21]. The presence of these metals, therefore, may account for the growth differences seen between plant treatments. Further investigation is required to determine whether these metals can further permeate the food chain and thus have broader ecosystem effects [20].

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