

Managing sources, sinks and transport of natural contaminants in regulated rivers: a case study in the Murrumbidgee River catchment, NSW

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Abstract

Environmental flows are assuming a central role in the sustainable management of Australian rivers. These flows are intended to recreate a flow regime and habitats which existed before the onset of flow regulation. Such flows, however, are now being implemented in a highly modified landscape, resulting in drastic changes to contaminant cycles which are now highly dependent on regulated, in-channel flows. This study examines the dynamics of contaminants (nutrients and salts) in each of three major riverine habitats; water column, sediments and biofilms, to identify sub-catchments with the highest potential for supplying salts to the main stem of the Murrumbidgee River, south-eastern Australia. Concentrations of contaminants in the sediments and biofilms were two orders of magnitude higher than in the water column in all sites, highlighting their importance as a sink for salts during low flows, and a potential source during in-stream freshes. By managing the timing and magnitude of regulated flow releases, environmental flows could be used to either enhance in-stream productivity by scouring nutrients and salts from in-channel habitats, diluting high loadings of unwanted contaminants (salts) transported from degraded sub-catchments, or reduce nutrient availability for downstream foodwebs by diluting nutrient rich floodwaters from catchment scale runoff events.

Keywords

Environmental flows, ionic composition, salt balance, primary production.

Introduction

Changes to the patterns of disturbance in rivers through flow variation and altered land-use practices have resulted in dramatic impacts on biodiversity and ecological processes in riverine landscapes (Ward, 1998; Bunn & Arthington, 2002). Furthermore, the connectivity between the river and its catchment has been substantially altered resulting in many rivers now containing highly modified sources and concentrations of natural contaminants such as nutrients, salt, and suspended sediment. Such changes have a significant effect on riverine biogeochemical cycles (e.g., nutrients, salts, organic matter) leading to changes in in-stream processes, and food chain structure and function (Robertson *et al.*, 1999). However, the relationship between flow regime, and the sources, sinks and transport of contaminants are poorly understood, making it a difficult task to predict the outcome of managed flow releases for river rehabilitation initiatives.

For rivers in which ecosystem processes have been degraded by flow regulation and water extraction, rehabilitation efforts aim to preserve biogeochemical and life-history cycles through the return of at least part of the natural flow regime (Poff *et al.*, 1997). In Australia, environmental flows are assuming a central role in the sustainable management of Australian rivers. These flows are intended to recreate a flow regime and distribution of habitats which existed before the onset of flow regulation. Such flows, however, are now being implemented in a landscape which has been highly modified. Contaminant loads now have an altered biochemical composition from their original state (Harris, 2001), and are highly dependent on in-channel regulated flows. Therefore, using environmental flows as artificial floods in regulated rivers has the potential to mobilise and transport nutrients and salts stored within the channel during low flows (Ryder *et al.*, 2006). Identifying sub-catchments with potential to contribute high loadings of contaminants, where the contaminants are stored within the channel, and the flow regime necessary to mobilise them is necessary for effective management of contaminant cycles.

This study quantifies the concentration of total and dominant salts (Ca, Mg, K, Na) in each of three major habitats; (i) water column, (ii) surface sediments and (iii) biofilms (algal slime attached to rocks and logs) under low flow conditions to identify catchments with the highest potential for supplying salts to the main stem of the Murrumbidgee River, south-eastern Australia. We predicted that algal biofilms and surface sediments, particularly in unregulated tributaries, would be a major sink for salts under low flow conditions.

Methods

Study site

The Murrumbidgee River is in south-eastern Australia, is a major tributary of the Murray-Darling River system and has a total catchment area of 84 000 km² (Fig. 1). It flows over 1500km from its source in the Snowy Mountains to its confluence with the Murray River. The Murrumbidgee is a heavily regulated river with 26 dams and weirs, and over 10 000km of irrigation canals (Kingsford, 2003). The large capacity Burrinjuck (1 026 000 ML) and Blowering (1 600 000 ML) Dams both provide irrigation releases, and stock and domestic water to the lower Murrumbidgee catchment. Maximum mean discharge (1970-1998) of 12700 ML d⁻¹ occurs at Wagga Wagga, reduced downstream to 4178 ML d⁻¹ at Balranald due to anabranches, distributaries, irrigation diversions and evaporation (Page *et al.*, 2005). This study focuses on the 657 km stretch of the Murrumbidgee River and its main tributaries from Burrinjuck Dam to Carrathool. The 'Murrumbidgee Catchment Blueprint' (2002) and subsequent 'Murrumbidgee Catchment Action Plan' (MCAP, 2005) both highlighted the need to develop maps that outlined priority sub-catchments for salinity management. Based on the 'Murrumbidgee Catchment Management Authority Case Study – application of statewide standards and targets' (2004) and research data that were regarded as "isolated, sporadic or completely absent" (MCAP, 2005) 12 sub-catchments were priority listed. However, this project sought to delve deeper into the ionic composition of salts, and where they occur within and among streams to establish if priority catchments also had significant stores of salts within the stream channel.

Sampling regime

Ten sites on representative tributaries and along the main stem of the Murrumbidgee River were sampled in February 2005 at the cessation of irrigation flows, and at base flows in tributary streams (Table. 1). At each site, triplicate samples were collected for: i) filtered water (0.45 µm) in 125 mL acid washed vials from 5cm below the surface of flowing water, ii) 3.9 cm³ surface sediment cores (19.6 cm² x 0.2cm deep) from permanently submerged in-stream sediments, and iii) 19.6 cm² cores of algal biofilms from permanently submerged cobble (in upland reaches) and wood (in lowland reaches) substrata. All samples were immediately frozen for transport to the laboratory. Surface waters were measured in situ for electrical conductivity (EC) µS cm⁻¹ using a TPS Conductivity-pH meter, turbidity (NTU) using a Hanna Instruments Turbidity meter, and in vitro for total nitrogen (TN) and total phosphorus (TP) from 125mL of unfiltered water samples using APHA (1998) standard methods. Mean daily discharge was calculated from NSW Department of Natural Resources (DNR) data located at <http://waterinfo.nsw.gov.au>.

Laboratory methods

Sediment and biofilm samples were defrosted in a 4°C refrigerator, placed in crucibles and dried at 80°C in a Contherm Series oven for 48 hours. Each sample was homogenised with a mortar and pestle and a 1.0g subsample removed for analysis. Water samples remained frozen and were defrosted immediately before analysis. All samples were digested in a Milestone MLS 1200 mega-microwave prior to analysis for Potassium, Magnesium, Calcium and Sodium using high performance liquid chromatography (HPLC) online to the Perkin Elmer ELAN 6000 inductively coupled plasma mass spectrometry (ICP-MS) at CSIRO Adelaide. For each cation, water column concentrations were converted to mg L⁻¹, and sediment and biofilm samples to mg kg⁻¹. A known volume of subsample was removed from each biofilm sample prior to drying and analysed for chlorophyll *a* using the methods outlined in Ryder *et al.* (2006). Data were converted to chlorophyll *a* mg m⁻². The analysis of variance for total cation concentration in each habitat as the dependant variable, and linear regressions were calculated using Statistix version 8.

Results

Distribution of dominant salts

The most notable result is the consistent pattern across all sites of high concentrations of Sodium in the water column and negligible concentrations stored in biofilm and sediments. Similarly, Sodium and Calcium dominate the water column, contributing over 75% of the total salts. In line with our prediction, we found substantial concentrations of salts (dominated by Calcium) in surface sediments and biofilms (up to 19 000 mg kg⁻¹) in all sites, highlighting their importance as a store of contaminants during low flows and a potential source during in-stream freshes.

Total water column concentrations of salts were not significantly different ($P>0.05$) among all sites on the main stem of the Murrumbidgee River from Burrinjuck Dam to Carrathool, with total salt concentrations consistently less than 20mg L⁻¹ (Fig. 1). This is despite a range of discharges from 600ML day⁻¹ at Nanangroe, 7681 ML day⁻¹ at Wagga and 764ML day⁻¹ at Carrathool at the time of sampling (Table 1). The Tumut River had the lowest concentration of water column salts at 4.5 mg L⁻¹ and shows the potential to dilute the salt concentrations contributed to the main stem of the Murrumbidgee by upstream tributaries during catchment runoff flow events. The reduced concentrations of salts at Gundagai (immediately downstream of the confluence with the Tumut) are evidence of this potential. Ionic composition of main stem sites was consistently dominated by Sodium and Calcium. This suggests that the high concentrations of suspended salts in tributary streams (Jugiong Creek 201 mg L⁻¹ and Muttama Creek 385 mg L⁻¹) play a minimal role in salt loads to the Murrumbidgee River during base flows or irrigation releases. Tarcutta Creek has also been identified as a priority sub-catchment for salinity, however under base flow conditions has water column concentrations more similar to the Murrumbidgee main stem at 35 mg L⁻¹.

Table 1. Locations, mean daily discharge for the 30 days prior to sampling (ML d⁻¹) and surface water chemistry for the ten sites sampled in the Murrumbidgee catchment.

Site	Easting	Northing	Discharge ML d ⁻¹	EC (mS/cm)	Turb. (NTU)	TP (mg L ⁻¹)	TN (mg L ⁻¹)
Murrumbidgee River @ Nanangroe	639 330	6 136 740	600	186	4.9	0.02	0.95
Jugiong Creek @ U/S Hume Highway Bridge	622 690	6 145 510	0.04	1046	39.7	0.03	2.03
Muttama Creek @ Coolac	606 110	6 133 025	0.02	2080	10.6	0.10	0.44
Tumut River @ Brungle Bridge	608 250	6 123 150	6507	31	3.7	0.01	0.15
Murrumbidgee River @ Gundagai	605 450	6 124 500	7033	73	3.5	0.08	0.26
Tarcutta Creek @ Old Borambola	559 700	6 108 500	11	402	12.8	0.05	0.35
Murrumbidgee River @ Wagga Wagga	528 200	6 115 600	7681	97	8.3	0.03	0.22
Murrumbidgee River @ Narrandera	484 850	6 140 105	3393	82	8.1	0.04	0.21
Murrumbidgee River @ Darlington Point	431 700	6 169 200	1252	88	9.8	0.04	0.36
Murrumbidgee River @ Carrathool	354 500	6 186 700	764	65	7.7	0.04	0.32

Relationship between ionic composition and in-stream primary production.

Although biofilms and sediments contain little Sodium, they contain proportions of Calcium>Magnesium>Potassium; each of which are important trace elements necessary for benthic metabolism. However, Calcium concentrations appear to be the dominant salt driving productivity, showing a significant positive correlation (R^2 0.43, $P<0.05$) with biofilm chlorophyll *a* (Figure 2). Similarly, Sodium concentrations appear to have a negative effect on in-stream primary production, with a significant negative correlation (R^2 0.43, $P<0.05$) with biofilm chlorophyll *a* (Figure 2). Overall, there is no significant correlation between total ionic composition or nutrient concentration (Table 1) and benthic production across the ten sites, highlighting the importance of understanding the composition of the salts across catchments.

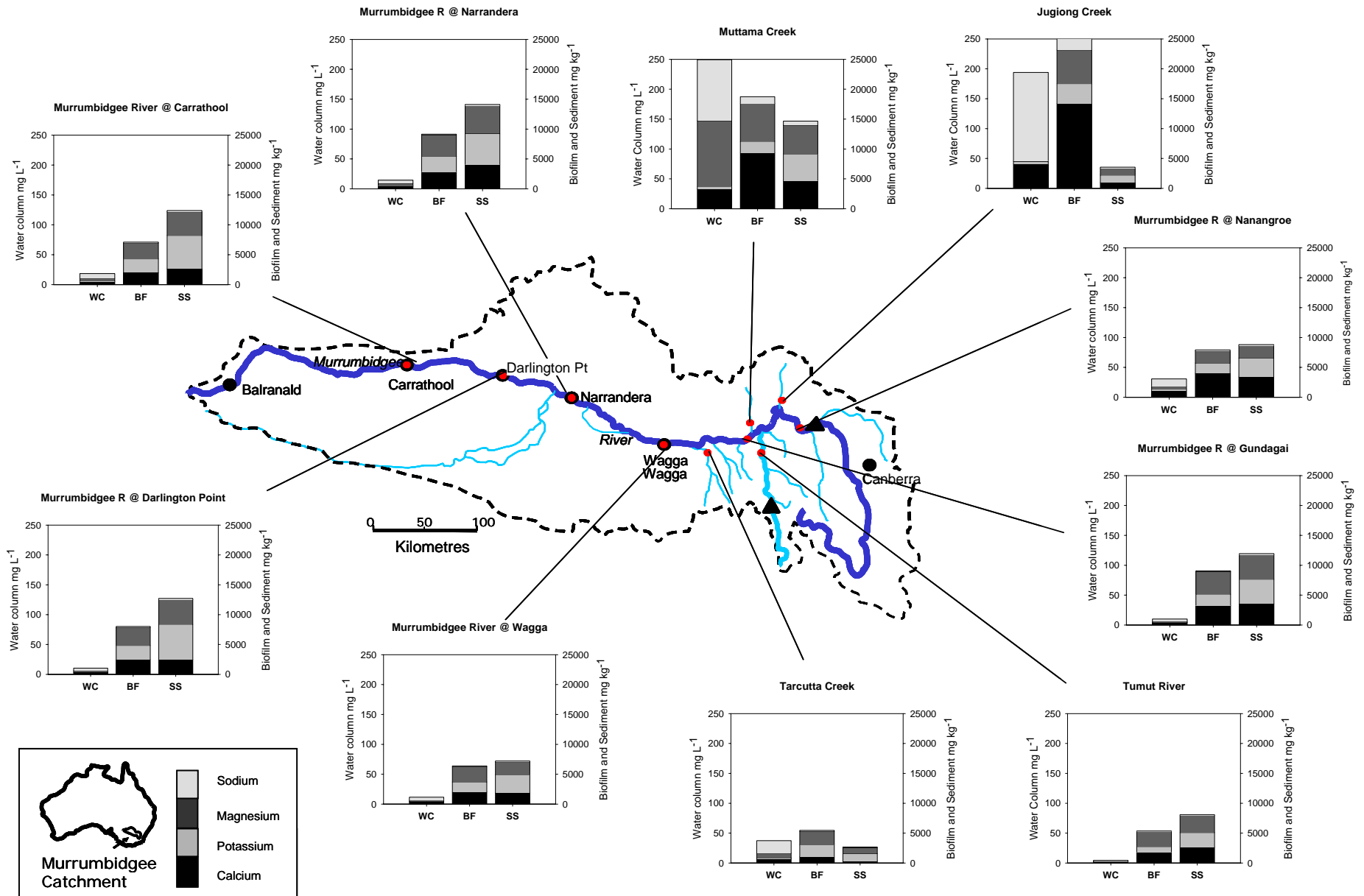


Figure 1. Concentrations of Calcium, Potassium, Magnesium and Sodium in the water column (WC), algal biofilms (BF) and surface sediments (SS) at ten sites throughout the Murrumbidgee catchment.

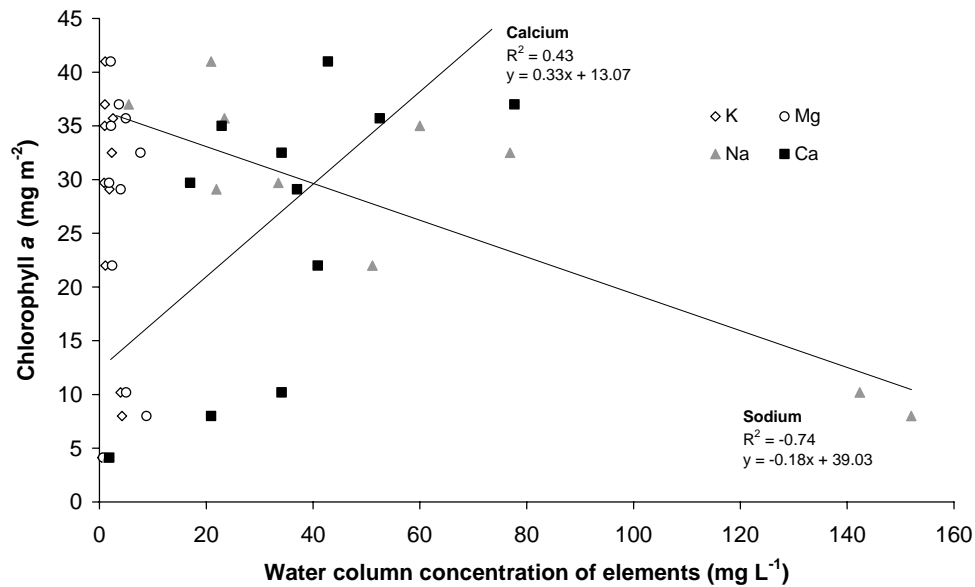


Figure 2. Relationship between Calcium, Potassium, Magnesium and Sodium in the water column and benthic chlorophyll *a* concentrations at ten sites throughout the Murrumbidgee catchment.

Discussion

The inorganic chemistry of each habitat reflects the time-scales of the processes for incorporation as well as the loss of the cations from the different environments. The water column has the shortest time-scale and is driven by the variations in the character and source of the inputs. In the case of the Murrumbidgee, the principal sources are the two major storages (Burrinjuck and Blowering) delivering to the Murrumbidgee upstream of Gundagai. The time scale for biofilm formation is about one month (Ryder, 2004), and the inorganic content of the biofilm reflects an integration of the biological processes for algal growth and biofilm formation, as well as the ambient water column chemistry integrated over this time, together with chemistry of fine sediments within the water column which have been incorporated into the biofilm matrix without undergoing reaction (Freeman *et al.*, 1995). The results from this study indicate that biofilms and surface sediments are a significant store of contaminants that are biogeochemically distinct from the water column, containing relatively small concentrations of Sodium, and high concentrations of Calcium, Magnesium and Potassium.

Ryder *et al.*, (2006) have demonstrated that velocities as low as 0.3 to 0.55 m sec^{-1} were sufficient to significantly reduce biofilm biomass in low gradient regulated rivers, releasing the salts and nutrients stored within these habitats to the water column. This suggests that environmental flow releases in the Murrumbidgee River have the potential to mobilize these contaminants from surface sediments and biofilms and may result in shifts in main stem biogeochemistry and subsequent changes to in-stream productivity and food webs.

At present, the calculation of salt and nutrient balances in river systems is through a concomitant knowledge of water column chemistry and discharge measured from known locations (McKee *et al.*, 2000) or modelled from existing datasets (Cuffney, 1988). These methods have been used to create salt balances for the Murray River (Chartres *et al.*, 2003) and nutrient balances for coastal streams in New South Wales (Harris, 2001). However, not all salts are the same, as this study has shown that high concentrations of Sodium can be detrimental to primary production, while Calcium can stimulate in-stream primary production (Figure 2) under certain conditions. Similarly, contaminant transformation will take place through organisms fixed in space such as biofilms (slime attached to logs, rocks, and sediment), and by water column primary producers such as algae which are transported with flow. Armed with knowledge only of the suspended load, current contaminant balances may substantially underestimate the potential loadings of salt and nutrients mobilised during natural or environmental flow releases. For example, we would hypothesise that the low stores of

contaminants in in-stream biofilms and surface sediments in Tarcutta Creek relative to Muttama and Jugiong Creeks would result in substantially lower loadings of contaminants entering the Murrumbidgee River from similar flow events from Tarcutta Creek. We propose that knowledge of the ionic chemistry of stored and suspended salts is required for prioritizing catchments for rehabilitation or for the timing of releases from impoundments for environmental purposes.

Our results indicate that catchment run-off events that mobilise contaminants stored in biofilms and sediments in tributaries will have quite a different chemical character to artificial floods from dam releases, and consequently a quite different ecological significance. By managing the timing and magnitude of regulated flow releases, environmental flows could be used to enhance in-stream productivity by scouring nutrients and salts from in-channel habitats or diluting high loadings of unwanted contaminants (salts) transported from degraded sub-catchments. There is also the potential to dilute catchment scale runoff events by piggy-backing natural flows with nutrient poor releases from headwater dams, a management option that may be counter productive to the aims of improving the ecological condition of river systems by reducing nutrients transported to downstream foodwebs.

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