INLINE POND TREATMENT PERFORMANCE AND LONGITUDINAL INSTREAM MONITORING IN A STORMWATER-AFFECTED URBAN WATERWAY

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ABSTRACT

Addington Brook in Christchurch, receives stormwater runoff from a 246 ha catchment of mixed industrial/commercial/residential land use. Instream water quality monitoring has shown elevated suspended solids, metal and nutrient concentrations along the brook, which is thought to be a major contributor of these pollutants to the Ōtākaro/Avon River and downstream estuary. Water quality and flow data from four different sites in Addington Brook during storm events were analysed to a) evaluate the performance of an inline, 18-year-old stormwater treatment pond in the upper catchment, b) evaluate spatial and temporal relationships between rainfall, instream flow and pollutant concentrations along the stream that could help prioritise mitigation strategies in different areas of the catchment, and c) evaluate the ability of the Modelled Estimates of Discharges for Urban Stormwater Assessment (MEDUSA) pollutant load model to predict pollutant source contributions. The pond performance analysis revealed significant (p 0.0001-0.04) removal of dissolved metals, solids and nutrients, demonstrating the ongoing effectiveness of pond systems for removing dissolved pollutants. However, discharge of untreated stormwater downstream of the ponds resulted in higher pollutant concentrations in the lower catchment. Pollutant rates of up to 5.2 g/min zinc (Zn), 0.2 g/min copper (Cu), 53 mg/min lead (Pb), 25 kg/min total suspended solids (TSS), 121 g/min total nitrogen and 28 g/min total phosphorus were measured where the brook converges with the Ōtākaro/Avon River. Dissolved Zn concentrations (by an order of magnitude), and to a lesser extent dissolved Cu, consistently exceeded the relevant guidelines for healthy urban waterways at all sampling sites, substantiating an earlier study that used MEDUSA to identify sources of high solids and metal loads in this catchment. The similarity of measured pollutant loads to the MEDUSA-predicted loads indicates that MEDUSA is effective at predicting the amount and origin of dissolved Zn and dissolved Cu in the catchment.

KEYWORDS

Urban waterway, instream pollutants, stormwater retention pond, MEDUSA

PRESENTER PROFILE

Frances Charters is a lecturer in the Hydrological and Ecological Engineering Research Group in the Department of Civil and Natural Resources Engineering, University of Canterbury. She comes from an industry background (in engineering design consultancy) and has more recently been researching at-source stormwater quality characterisation and pollutant load modelling.

1 INTRODUCTION

Impermeable urban surfaces such as roads, carparks and roofs contribute pollutants via untreated stormwater runoff to urban waterways, causing a wide range of adverse effects on the aquatic ecosystem. Total suspended sediment (TSS), metals such as copper (Cu) and zinc (Zn), and nutrients, have been identified as the key pollutants of concern in urban waterways. Addington Brook is a very good example of such an urban waterway. Addington Brook, which receives stormwater runoff from a 246 ha catchment of mixed industrial/commercial/residential land use, ultimately flows into the Ōtākaro/Avon River. Historically, instream water quality monitoring has identified elevated solids, heavy metals and nutrient concentrations in the brook (Margetts 2014, Margetts and Marshall 2015) and it is thought to be a major contributor of these pollutants to the Ōtākaro/Avon River and the downstream Ihutai/Avon-Heathcote Estuary. Detailed pollutant load modelling and at-source stormwater quality characterisation within the Addington Brook catchment has identified roads and carparks as key sources of solids, galvanised roofing as the dominant source of dissolved zinc, and carparks as the key source of dissolved copper (Charters 2016, Charters et al. 2016).

This study analysed instream water quality (and some flow data) at different sites along ~3 km of Addington Brook, to evaluate longitudinal spatial and temporal patterns of pollutant levels within the catchment during wet weather. The treatment performance of the 18-year-old Matipo stormwater retention ponds at the top of the catchment was also assessed and compared with previous performance data (EOS Ecology 2009) to assess the ability of an established pond system to remove pollutants 18 years post-construction as well as to evaluate any change in performance since the last performance monitoring 8 years ago. Pollutant loads (using concentration and flow data) were assessed at one of the sites by comparing measured data with event loads predicted using the Modelled Estimates of Discharge for Urban Stormwater Assessment (MEDUSA) model (Charters 2016, Charters et al. In review).

2 METHODOLOGY

Addington Brook was sampled by Environment Canterbury (ECan) at four sites (Figure 1) during four wet weather events in the spring and summer of 2015-2016 (Table 1). The Matipo Up-Stream (US) pond sampling site was used to capture mixed water quality received from roof, roads and carparks at the top of the catchment entering the first-flush wetland zone of the pond system. The Matipo Down-Stream (DS) pond sampling site was used to capture the outflow from the downstream detention pond and was used to generally evaluate the stormwater pond system's overall performance. It is noted, however, that there are a number of stormwater inputs throughout the system effectively short-circuiting the full treatment train (City Design 1999, EOS Ecology 2009). The catchment upstream of the Matipo pond is largely impervious with activity mainly from the road-rail freight handling facility and neighbouring industrial/commercial activity. The pond system was designed to detain and treat (to an undefined level) 21.7 ha of runoff from the catchment (City Design 1999, EOS Ecology 2009). The Deans Ave site captures the majority of runoff from the industrial/commercial sector within the Addington catchment. The Riccarton Ave site is located furthermost downstream in Hagley Park, just before it enters the Ōtākaro/Avon River. Between the Deans Ave and Riccarton Ave sites there are inputs from a number of stormwater pipes draining commercial/residential land, as well as runoff from sports fields in Hagley Park.

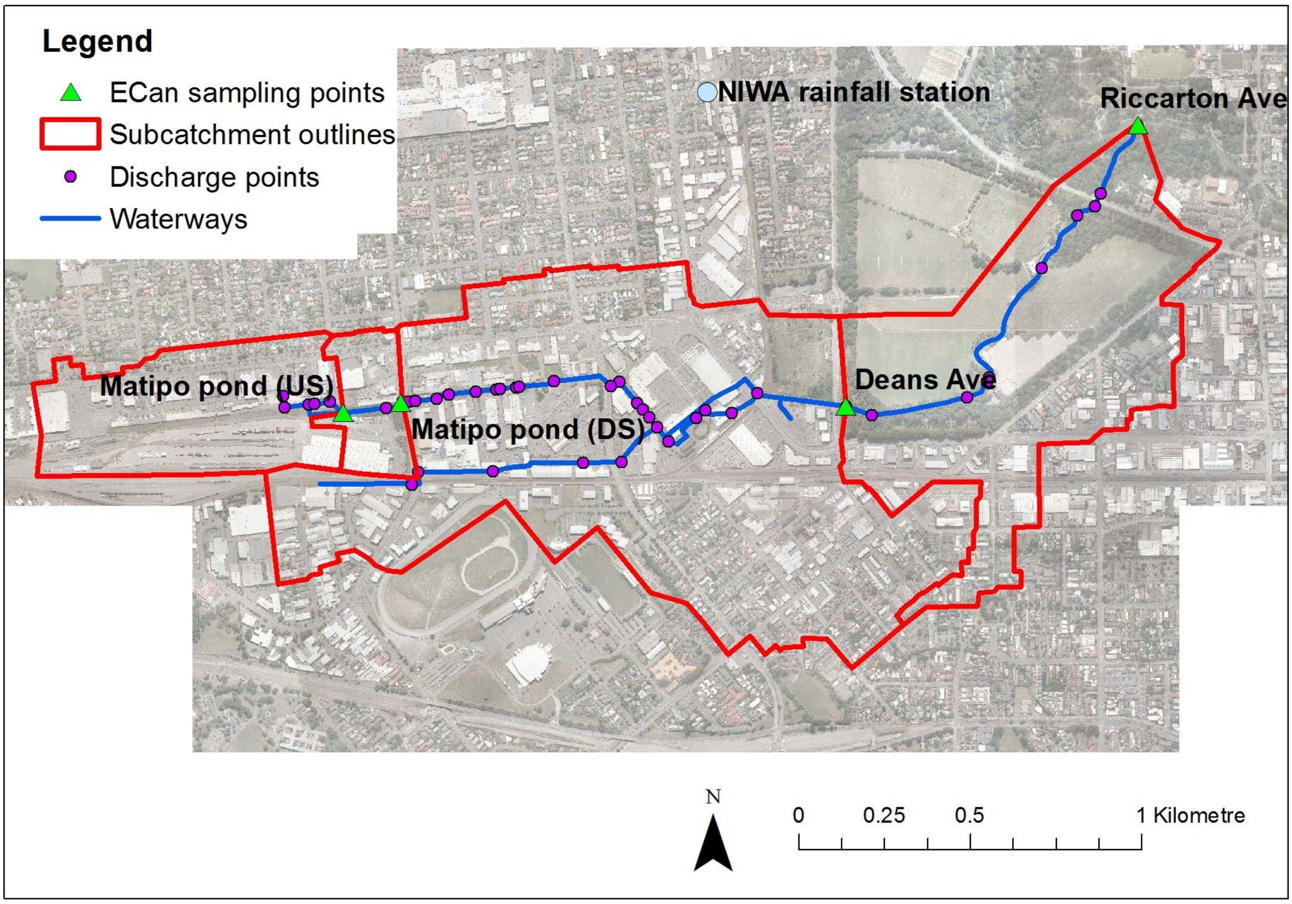

Figure 1: Sampling sites, sub-catchments and NIWA rainfall station (Kyle Street) within the Addington catchment

Rainfall data were derived from records provided by the National Institute for Water and Atmospheric Research (NIWA), while water level was recorded by ECan at all sites along with flow at Riccarton Ave. Water samples were collected by ECan throughout each storm event (to capture the onset, peak and end periods) using automatic samplers triggered by a rise in water level following rain. Between 3 and 6 samples were taken for water quality analyses during each of the four rain events. All samples were analysed for total suspended solids (TSS), dissolved metals (zinc (Zn), copper (Cu) and lead (Pb), as dissolved metals are the more bioavailable and eco-toxic form) and nutrients (total nitrogen (TN), ammonium-nitrogen (NH_4^+-N) and total phosphorus (TP)). For the Matipo US and DS sites, samples were also analysed for dissolved reactive phosphorus (DRP), total kjeldahl nitrogen (TKN), nitrate + nitrite nitrogen (NNN) and turbidity, to further characterise pond performance and treatment mechanisms.

Comparison of pollutant concentrations between the overall inflow (Matipo US Pond) and outflow (Matipo DS Pond) was made based on samples taken approximately 5-9 minutes apart. This was based on previous observations (EOS Ecology 2011) that the hydraulic retention time in the first flush wetland basin was a matter of minutes and comparison of the pond treatment efficiencies by EOS Ecology (2011) were also based on approximately the same time intervals between inflow and outflow.

Table 1: Summary rainfall parameters for the monitored storm events[1]

Rainfall parameters	**Event**			
	1	**2**	**3**	**4**
Date	18-20 Sep 2015	11-12 Nov 2015	15-16 Jan 2016	27-28 Jan 2016
Start	19:45, 18/9	17:45, 11/11	19:45, 15/1	20:45, 26/1
Finish	10:15, 20/9	12:15 12/11	9:30, 16/1	4:45, 28/1
Average intensity (mm/hr)	0.8	0.5	0.9	0.9
Peak 15-min intensity (mm/hr)	5.7	2.5	4.4	20.5
Antecedent dry days (ADD)	7.8	13.2	12.1	7.6
Duration (hrs)	38.5	18.5	13.8	32.0
Total rainfall depth (mm)	30.7	9.4	12.2	28.3

[1] Where rainfall at the start of an event was <0.1 mm in a 5-min. interval, it was not considered an event.

Instream mixed pollutant concentrations were compared against relevant Land and Water Regional Plan (LWRP) values for a 'spring-fed-plains-urban' waterway. This study's results have also been compared against previous instream monitoring data collected by Christchurch City Council (CCC) at Riccarton Ave. They have sampled at that site since 2008 on a monthly basis, i.e. under a range of stream flow conditions, and have also sampled during specific wet events in 2013 and 2014 (Margetts 2014, Margetts and Marshall 2015).

Instream pollutant loads were calculated for the Riccarton Ave site as both flow data and pollutant concentration data were collected at this site. The formula for load calculation is:

Load (g/min) = Flow at sampling time point (m^3/min) x Concentration (g/m^3)

Calculated loads and event duration across all 4 sampling events were then used to provide an average pollutant event load (in g). These loads were compared against the pollutant loads predicted by the Modelled Estimates of Discharge for Urban Stormwater Assessment (MEDUSA) model (Charters et al. In review) to be generated from the impermeable roof, road and carpark surfaces in the catchment. MEDUSA was run for 88 rainfall events from the year 2012, as rainfall pH, average event intensity, antecedent dry periods and event duration data were available (Charters 2016). The predicted event loads were then averaged to find a median event load for each modelled pollutant.

3 RESULTS

3.1 RELATIONSHIP BETWEEN RAINFALL, INSTREAM FLOW AND POLLUTANT CONCENTRATIONS

The water level at each site responded in a similar profile to rainfall, with a short delay of increased water level following measured rainfall, showing the significance of stormwater inflows into the Brook. The comparative change in water level during rain events at the US and DS pond sampling sites indicates that some attenuation of flow is occurring through the Matipo pond system (Figure 2). Instream flow data from the Riccarton Ave site showed a consistent increase in flow with periods of rain, with a time lag of around 1.5-2 hours (Figure 3).

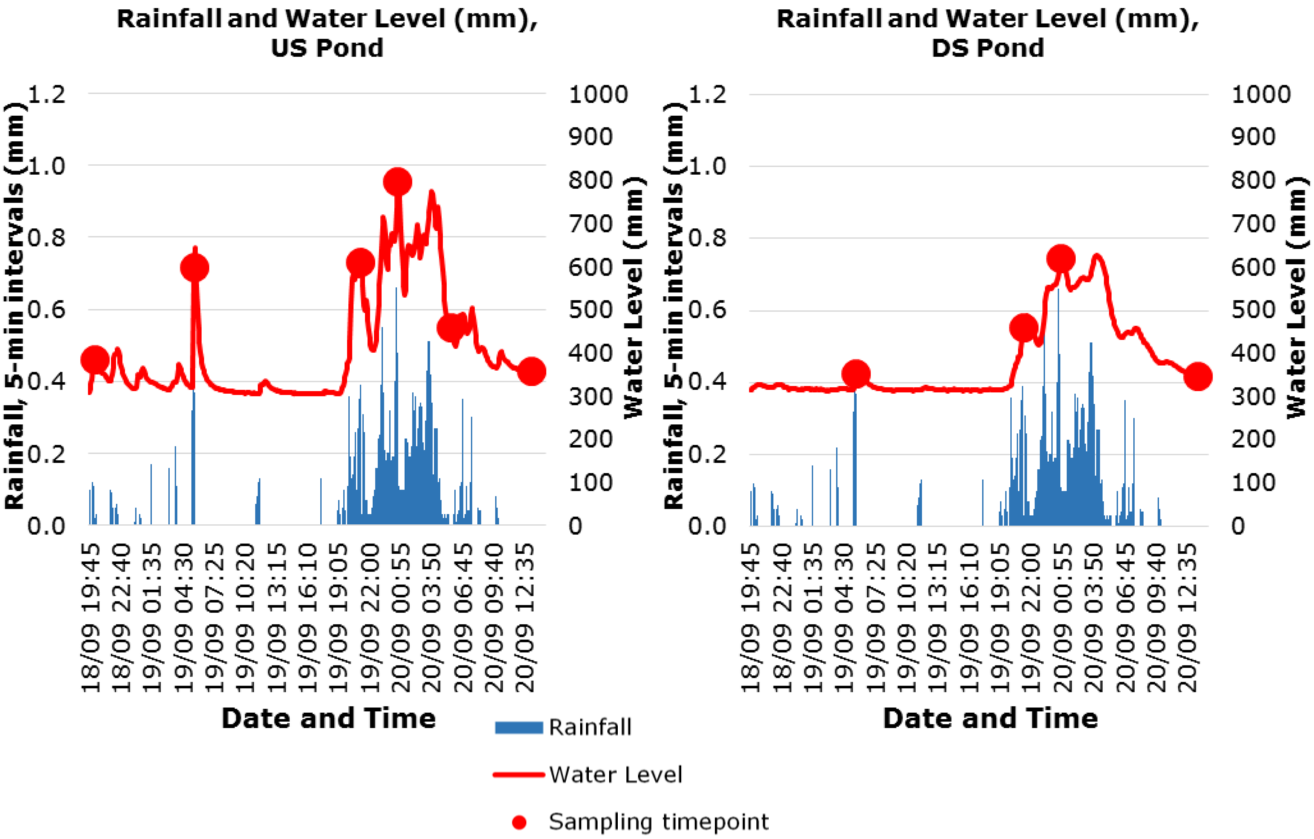

Figure 2: Comparative rainfall, water level and sampling times for Event 1 (19-20 September 2015) at the inflow (left) and outflow (right) of the Matipo pond

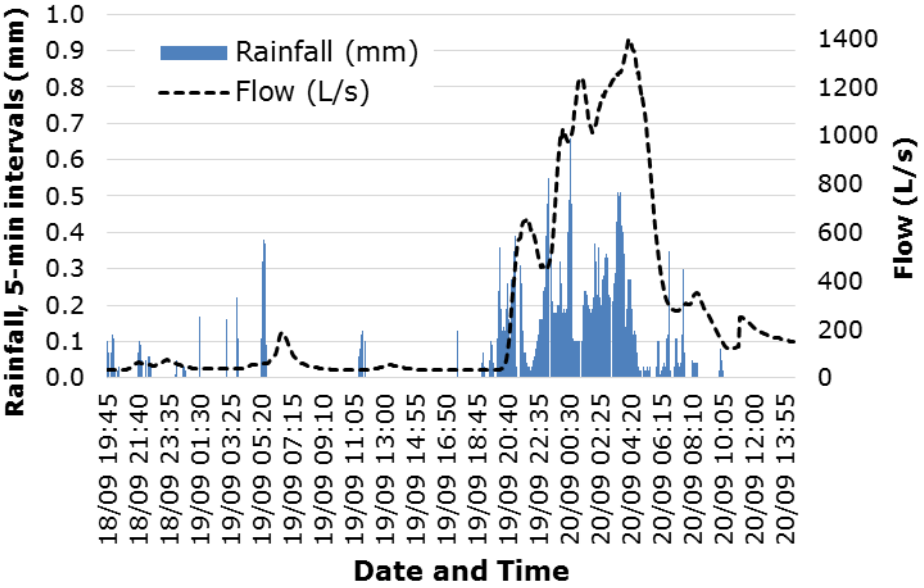

Figure 3: Comparative rainfall and stream flow for Event 1 (19-20 September 2015) at the Riccarton Ave sampling site

3.2 LONGITUDINAL ANALYSIS OF POLLUTANT CONCENTRATIONS

Significant variability was found in the pollutant concentrations during each sampled event. Concentrations of particulate pollutants were typically highest at the start of the sampled rain events, indicating the presence of a ‘first flush’ wash-off effect from contributing impervious surfaces.

Upstream of the Matipo pond, TSS concentrations were above the median LWRP guideline value of 25 mg/L (Figure 4). Total suspended solids were significantly reduced in the Matipo ponds, however, concentrations then increased downstream. The Riccarton Ave TSS concentrations were the highest of the four sampling sites. Between Deans Ave and Riccarton Ave, the brook receives runoff from a mix of commercial and residential areas, including road runoff from Hagley Ave, and it is also possible that sediment may be entering the stream directly along this section from bankside erosion, as the banks are steep and unstable in some reaches.

Similarly, dissolved Zn was elevated at the inflow to the Matipo pond, with all samples across the four rain events well above the LWRP guideline value (Figure 4). Although the ponds retained a lot of this dissolved Zn, some samples from downstream of the pond had dissolved Zn concentrations above the guideline value. Between the ponds and Deans Ave there was further contribution of dissolved Zn from the subcatchment to the large subcatchment between the ponds and Deans Ave receives stormwater runoff from most of the industrial/commercial area within the catchment. Large galvanised roof areas in this subcatchment contribute very high concentrations of Zn, mainly in dissolved form to the stormwater (Charters (2016). Dissolved Cu concentrations followed a similar pattern to dissolved Zn. However, the concentrations were not as elevated in relation to the LWRP guideline value as found for dissolved Zn. Dissolved Pb concentrations were well below the LWRP guideline value of 15.5 µg/L for all samples at all sites, and therefore are not discussed any.

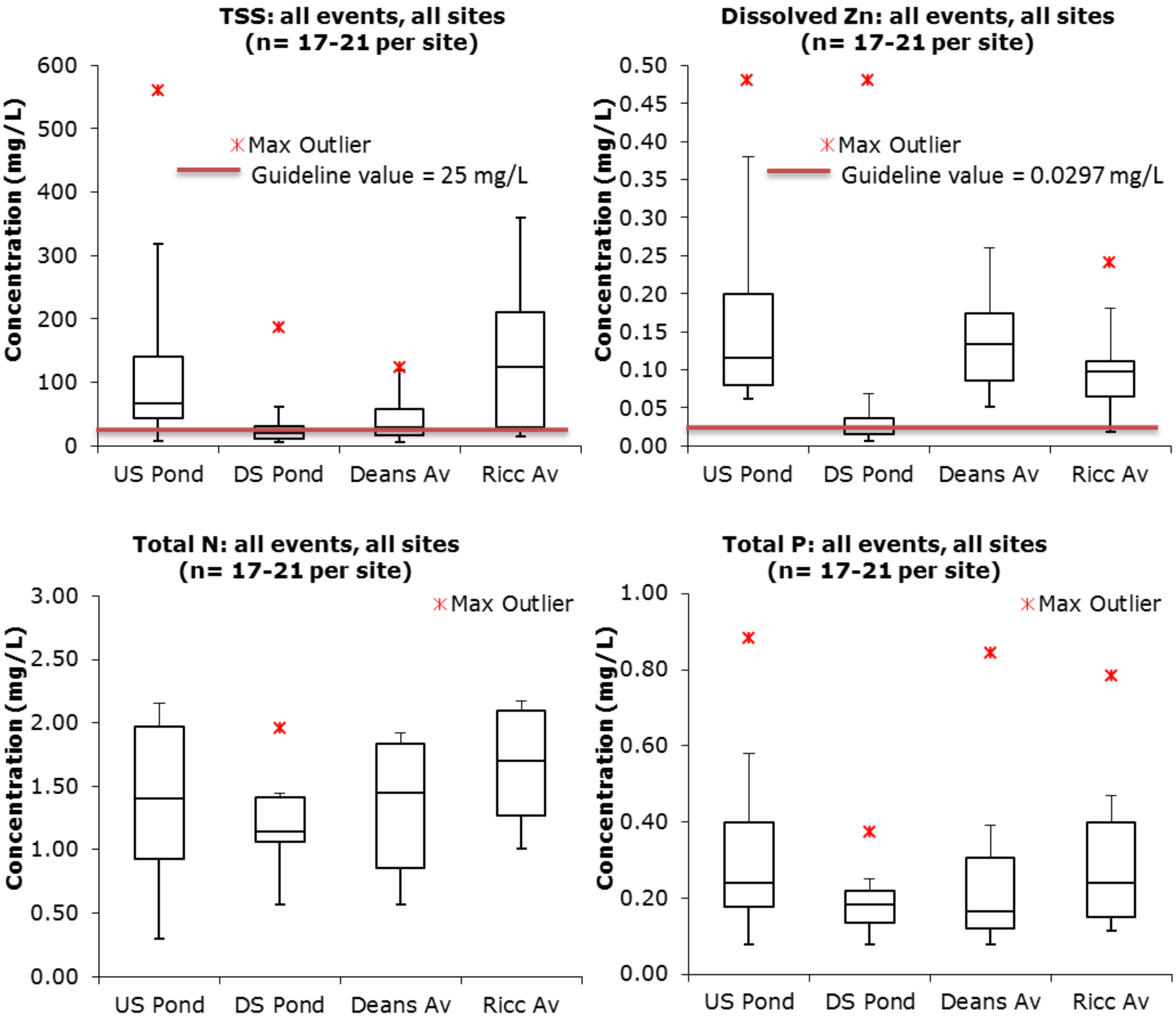

Figure 4: Ranges of TSS, dissolved Zn, total N and total P concentrations at each sampling site, compared against relevant LWRP guideline values where available (red line)

3.3 POLLUTANT LOADS

The flow and pollutant concentration data at the Riccarton Ave site were used to calculate pollutant loads at that site. Overall, an average of 2.3 kg dissolved Zn per event and 84 g dissolved Cu per event was measured in Addington Brook. This is comparable to the catchment load predicted by MEDUSA (Charters 2016), of 2.8 kg dissolved Zn and 45 g dissolved Cu. Given the simplification of the complex processes of pollutant build-up and wash-off necessary in the model, pollutant loads within the same order of magnitude confirms that the MEDUSA is effective at predicting the amount and origin of dissolved Zn, especially, and dissolved Cu in the catchment.

3.4 MATIPO STREET POND PERFORMANCE

In general, the ponds were found to be very effective at reducing TSS and dissolved metals. Dissolved metal concentrations in the pond outflow were found to consistently be below LWRP guideline values (Hardness Modified Trigger Values (HMTVs) for the Ōtākaro/Avon River of 29.7 µg/L dissolved Zn and 3.5 µg/L dissolved copper;

(Canterbury Regional Council 2015)), with the exception of 3 of the 17 samples. In comparison, the median inflow dissolved metal concentrations ranged from 80-210 µg/L dissolved Zn and 2.5-6.2 µg/L dissolved Cu. The pond provided an average reduction of 80% and 63% for dissolved Zn and Cu, respectively. Similarly, outflow TSS concentrations were found to be consistently below the LWRP guideline value of 25 mg/L (Canterbury Regional Council 2015)) for all but 5 of the samples. Median inflow TSS concentrations for each sampled event ranged from 55 to 165 mg/L, with an average reduction in TSS of 69% in the pond.

The ponds were not as effective at nutrient reduction, however, and a shift in nitrogen speciation occurred through the pond. Most of the TN comprised TKN in both inflow and outflow, however, inorganic NNN concentrations in the outflow were sometimes higher than in the inflow. This suggests some of the TKN was converting to NH_3-N (via mineralisation) and subsequent NH_3-N to the more soluble NNN form (nitrification). Elevated NNN can lead to excessive algal growth and therefore is of concern at elevated concentrations.

Most of the phosphorus in the inflow and outflow was in particulate form. However, DRP levels in the outflow still exceeded the LWRP guideline value (inflow median 0.08 mg/L; outflow median 0.04 mg/L; LWRP guideline value 0.016 mg/L). The relationship between particulate phosphorus and TSS concentration in both inflow and outflow samples did not show a consistent correlation ($R^2 = 0.34$ i.e. only 34% of the data can be explained by their relationship). This suggests that removal of TSS in the ponds cannot be assumed to result in a concurrent reduction of phosphorus.

The current performance was compared against the performance in 2008 (EOS Ecology 2009). The 2008 data was collected during winter, over 4 rain events. Inflow concentrations were similar between the two studies for TSS and nitrogen species, but for dissolved metals, the 2008 results were typically much higher. Both the 2008 study and this current study confirm that the ponds are continuing to perform effectively.

Table 2: Inflow and outflow water quality (median and ranges) reported in 2008 and 2015-16 studies

Water quality parameter	**Inflow concentration**		**Outflow concentration**	
	Current 2015-16 study	**EOS 2008 study**	**Current 2015-16 study**	**EOS 2008 study**
TSS (mg/L)	83 (55-165)	95 (61-140)	22 (6-30)	28 (7-51)
Dissolved Zn (µg/L)	130 (80-210)	673 (310-1,200)	20 (10-60)	154 (100-235)
Dissolved Cu (µg/L)	4.2 (2.5-6.2)	33.1 (13.0-56.5)	1.5 (0.5-1.9)	5.9 (2.9-10)
Dissolved Pb (µg/L)	0.3 (0.2-0.5)	19.8 (12.0-34.5)	0.2 (0.1-0.3)	4.7 (0.8-8.7)
TN (mg/L)	1.4 (1.3-2.0)	3.7 (1.1-8.3)	1.0 (0.6-1.2)	1.3 (1.0-1.7)
TKN (mg/L)	1.0 (0.8-1.6)	3.2 (1.0-7.8)	0.9 (0.4-1.1)	1.1 (0.8-1.3)
$NH4^+$-N (mg/L)	0.2 (0.1-0.5)	NA	0.1 (0.1-0.3)	NA
NNN (mg/L)	0.2 (0.1-0.4)	0.5 (0.08-1.0)	0.2 (0.1-0.3)	0.2 (0.1-0.3)
TP (mg/L)	0.3 (0.2-0.6)	NA	0.2 (0.1-0.2)	NA
DRP (mg/L)	0.09 (0.06-0.15)	NA	0.03 (0.01-0.06)	NA

NA: water quality parameter not analysed

4 DISCUSSION

While the Matipo ponds are effective at reducing dissolved metals, only a limited proportion of the total flow of the brook passes through these ponds and benefits from that treatment (i.e. runoff from only 30.9 ha (13%) of the 246 ha catchment). However, the continued effectiveness of the ponds, 18 years after construction, suggests that inline wet ponds could also be an effective treatment option in the lower reaches of the catchment.

The similarity between the predicted dissolved Zn and Cu loads being generating at source and the measured loads observed at the Riccarton Ave sampling site (i.e. near the Addington Brook confluence with the Ōtākaro/Avon River) suggests there is little immobilisation of metals from dissolved form within Addington Brook. MEDUSA modelling has identified galvanised roofs as the dominant contributor of dissolved zinc and carparks as the dominant contributor of dissolved copper (Charters 2016). The lack of instream immobilisation further reinforces the importance of effective source reduction and near-source management of these pollutants before they can enter the stream.

The use of a longitudinal sampling programme (i.e. monitoring at various locations within the brook) has proved very valuable in identifying hotspot subcatchments for each pollutant. Previously, the available data only showed that there was a pollution issue in the brook by the time it reached the Ōtākaro/Avon River. Such information is of limited use when developing a targeted stormwater management plan for the catchment to address the pollution issues (e.g. source reduction, treatment systems, policy implementation). With the spatial coverage provided by the longitudinal sampling and use of the MEDUSA model for identifying source contributions, the new data enables fit-for-purpose stormwater management solutions to be developed.

The use of automatic samplers was particularly effective at capturing stormwater variability during a rain event, in a safe manner (i.e. regardless of the time of rainfall). The flow data available at Riccarton Ave were also very useful for calculating instream pollutant loads from having concurrent flow data for each water quality sampling time point.

The substantial increase in TSS downstream of the ponds to the confluence of Addington Brook with the Ōtākaro/Avon River suggests bankside stability of the brook within Hagley Park may be a significant contributor of sediment. The TSS concentrations at Riccarton Ave were generally higher than those seen at Matipo US sampling point, suggesting there is an additional source of sediment beyond stormwater runoff in the lower reaches of the brook. Therefore, stormwater management improvements alone may not result in as significant reduction in TSS in the lower brook. There is likely to be a legacy of deposited sediment (and other pollutants such as metals) in these lower reaches that may become re-suspended under higher velocity stormflow conditions. As the brook passes through a public park, there is physical space and opportunity for stream form and stability improvements that could help address these issues.

5 CONCLUSIONS

This longitudinal study of instream wet weather water quality in a stormwater-impacted urban stream has provided valuable data that will aid the development of effective stormwater management plans. The 18-year-old Matipo Street retention ponds were shown to perform very well for TSS and dissolved metals reduction. Nutrient removal rates were not as high and analysis of the relationship between solids and total phosphorus concentrations in the ponds indicated that targeting solids removal is unlikely to effectively reduce nutrients. Therefore consideration needs be given to specific nutrient removal options when developing a catchment stormwater management plan.

Pollutant loads for dissolved zinc and copper were similar to the predicted (MEDUSA model) loads, highlighting MEDUSA's effectiveness at predicting stormwater pollutants in the catchment. This is valuable information when combined with the longitudinal instream data, as it guides the selection of appropriate treatment solutions in appropriate locations within the catchment.

The data also suggests there is little immobilisation of dissolved metals occurring in the brook between source and discharge into the Ōtākaro/Avon River. Therefore management of dissolved metals in stormwater is important to prevent eco-toxic effects on instream aquatic life.

The use of a longitudinal instream sampling approach, using automatic samplers and flow data, is a useful tool for identifying and then prioritising areas within a catchment for management improvements. In particular, flow data are important for both analysing pollutant loads, as well as quantifying opportunities to treat runoff in the catchment via retention and infiltration. Reducing runoff quantity as well as reducing pollutant concentrations will contribute to load reduction.

ACKNOWLEDGEMENTS

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