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Floating Treatment Wetland influences on the fate of metals in road runoff retention ponds

Karine E. Borne[a,*], Elizabeth A. Fassman-Beck[a], Chris C. Tanner[b]

[a] University of Auckland, Civil and Environmental Department, Private Bag 92019, Auckland Mail Centre, Auckland 1142, New Zealand

[b] National Institute of Water & Atmospheric Research, PO Box 11-115, Hamilton, New Zealand

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ABSTRACT

A field trial comparing the fate of metals in two parallel stormwater retention ponds, one of which was retrofitted with a Floating Treatment Wetland (FTW), was carried out near Auckland, New Zealand. Results suggest that the FTW increased metal accumulation in the pond sediment especially in summer due to lower sediment Eh, more anoxic water column, neutral pH and greater source of organic matter (OM) induced by the FTW. These factors combined with higher temperature enhanced metal sorption onto OM, flocculation of particulate pollutants, metal sulphide formation and reduced OM degradation and thus limited release of metals. Unlike Zn, Cu speciation in the pond sediment was relatively unchanged under various sediment Eh conditions due to its strong binding property with sulphide and OM. Occasional moderate metal release was detected from the FTW pond sediment likely due to aerobic OM degradation at the beginning of spring and/or hydroxides reduction when sediments became reduced later in the season. No release was noticed from the conventional pond sediment likely due to biosorption and/or uptake by algae which developed in the conventional pond and settled on the bottom sediment. Direct uptake by the plants of the FTW and sorption onto root plaques are not thought to be significant removal pathways. Nevertheless roots play a major role in trapping particulate pollutants, eventually sloughing off to settle on the bottom of the pond, and provide an adequate substrate for bacterial development due to release of organic compounds which are both essential for dissolved metal sorption and metal sulphide formation.

1. Introduction

Urban and industrial activities have increased watershed metal exports contributing to impaired receiving waters (Clark et al., 2007). Dissolved copper (Cu) and zinc (Zn) were found to be the primary cause of toxicity in highway runoff tested for five fresh water and marine species (Kayhanian et al., 2008). These metals are characteristically found at high concentrations in stormwater runoff from urbanized areas (San Francisco Bay Conservation and Development Commission, 2003; Timperley et al., 2005; Zgheib et al., 2011) presenting a common risk for receiving environments worldwide. Constructed wetlands and retention ponds are practices widely used to reduce suspended solids and metal concentrations before they reach the environment. Retention basins generally provide limited removal of dissolved contaminants, being more efficient at removing

* Corresponding author. Tel.: +64 9 373 7599x89555.
E-mail addresses: kbor019@aucklanduni.ac.nz, karine.borne@gmail.com (K.E. Borne).

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coarse, particulate-attached forms (Van Buren et al., 1996). Vegetated wetlands provide removal mechanisms for soluble pollutants and those associated with finer particles (Bavor et al., 2001); however, they usually require larger areas and will not tolerate extended periods of high water levels. A novel approach, the floating treatment wetland (FTW), offers a solution able to cope with these disadvantages.

A FTW is comprised of a porous floating mat planted with emergent macrophytes. Plant roots grow through the mat and hang into the water column. A FTW is typically installed on the surface of a pond and is suitable for new construction or retrofit installation. Several studies have identified nutrient and metal removal capabilities of FTWs (Stewart et al., 2008; Van De Moortel et al., 2010; Tanner and Headley, 2011). However there are limited published data on FTW performance and associated mechanisms for stormwater applications at field scale (Headley and Tanner, 2012). Three studies have addressed metals' treatment for concentrations similar to stormwater runoff (Van De Moortel et al., 2010; Tanner and Headley, 2011; Borne et al., 2013a), however they didn't specifically address the pollutant removal processes involved.

A field study with side-by-side monitoring of two geometrically similar retention ponds, only one of which contained a FTW with fully developed vegetation, was carried out over a 2-year period. Greater removal of total copper (TCu) and total zinc (TZn) from the incoming stormwater runoff has been reported for the FTW pond with median mass removal efficiencies of 36 and 57%, respectively, against 15 and 41%, respectively, for the Control pond (Borne et al., 2013a). The present paper investigates the fate of the trapped Cu and Zn through monitoring sediment (both ponds) and plant tissue (FTW pond only) metal concentrations. Sequential extraction of sediments and analysis of roots, root plaques and shoots, as well as Scanning Electron Microscopy (SEM) analysis of roots helped to identify the forms in which pollutant were trapped. Temperature, dissolved oxygen (DO), redox potential (Eh), pH and specific conductivity were monitored in both ponds to identify possible chemical reactions induced by the FTW. The data and discussion investigate in detail the key mechanisms induced by the presence of a FTW which are likely responsible for the enhanced performance compared to a conventional retention pond. Understanding the pollutant removal processes will help evaluate their sustainability and optimise performance.

2. Materials and methods

2.1. Site description

The study site and instrumentation have been described elsewhere (Borne et al., 2013a). Briefly, the experimental site is a stormwater retention pond located north of Auckland, New Zealand, and collects the runoff coming from a highway. The catchment is approximately 1.7 ha (75% impervious). The retention pond has been bifurcated into two straight-walled parallel sections (~100 m^2 each) with a permanent water depth of 0.75 m, in order to allow a side by side study. The accumulated sediments were dredged before refilling the pond, leaving a thick clay layer at the bottom. In one partition (FTW pond) an approximately 50 m^2 FTW planted with *Carex virgata* (~17 plants/m^2) was installed in December 2010 (summer in the Southern Hemisphere) (Fig. 1). The other partition remained as a conventional retention pond, to serve as a control (Control pond- Fig. 1).

2.2. Physico-chemical parameters measurement and water column sampling

DO, Eh, specific conductivity and pH were measured during dry weather in both ponds on 8 occasions: one week after the FTW was installed and then at approximately 3-monthly intervals (always at similar time in the morning). Fourteen and six measurements were made for each mission in the FTW and Control ponds, respectively, except during the last mission where seven measurements were made in the FTW pond. Detailed methodology is described elsewhere (Borne et al., 2013a). During the last sampling mission, one sample was collected below the FTW and in the middle of the Control pond and analysed for Chlorophyll A according to method 10200 H (APHA, 2011). Continuous temperature and DO monitoring was carried out below the FTW (at 10 and 40 cm depth) and in the Control pond (at 40 cm depth) at 15 min intervals using a D-Opto logger (Zebra-Tech Ltd, Nelson, NZ). Due to a thick deposit of sediment and bacterial development on the optical window of the permanently installed D-Opto logger in the Control pond in summer, readings became inaccurate and had to be discarded for this period of time.

2.3. Plant sampling and analysis

Plant biomass assessments were performed 8 times, on the morning following the dry weather water sampling missions. Concurrently, root and shoot tissue samples were collected in 11 locations over the FTW, except during the nine first months of growth when plants were still establishing. Six plants from the same batch as those originally planted in December 2010 on the FTW were analysed as a baseline. Biomass measurement and pollutant accumulation estimate are described elsewhere (Borne et al., 2013a, 2013b). Iron or manganese plaques can form on the surface of the root of wetland plants due to the action of bacteria and oxygen released through the roots (Emerson et al., 1999; Liu and Zhu, 2005). These plaques are known to bind metals, like Cu or Zn, which are in their

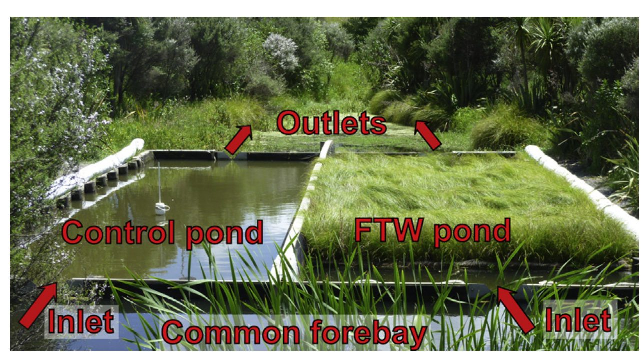

Fig. 1 – Control pond (left) and FTW pond (right) of the present study.