Floating treatment wetlands –an innovative solution to enhance removal of fine particulates, copper and zinc

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Reduction of metals, particularly copper and zinc, in urban stormwater has been identified as a priority to protect the health of aquatic ecosystems in the Auckland Region (Auckland Regional Council, 2004). Floating treatment wetlands (FTW), employing emergent plants growing on a mat floating on the water surface, rather than rooted in the bottom sediments, provide an innovative option for treating urban stormwaters.

Conventional stormwater treatment devices, such as ponds, have proven limited in their ability to remove the dominant dissolved and fine suspended particulate-associated metal fractions, which tend to be the most toxic to aquatic life (Griffiths and Timperley, 2005). Conventional surface-flow wetlands with sediment-rooted plants are susceptible to dieback due to excessive inundation and water level fluctuation. They therefore either need to occupy relatively large areas in order to buffer against extremes in water level fluctuation, or be preceded by a high-flow bypass system which means that only a portion of the flow receives treatment during large storm events.

Floating treatment wetlands (FTWs) employ rooted, emergent macrophytes (similar to those used in surface and subsurface flow wetlands) growing as a floating mat on the surface of the water rather than rooted in the sediments – see Figure 1. They are therefore able to tolerate the wide fluctuations in water depths that are typical of stormwater systems. The plant roots hanging beneath the floating mat provide a large surface area for biofilm growth and entrapment of fine suspended particulates that would otherwise remain in suspension in a pond system. Because the plants are not rooted in the sediment, they are forced to acquire their nutrition directly from the water column, which enhances potential rates of nutrient and element uptake into biomass.

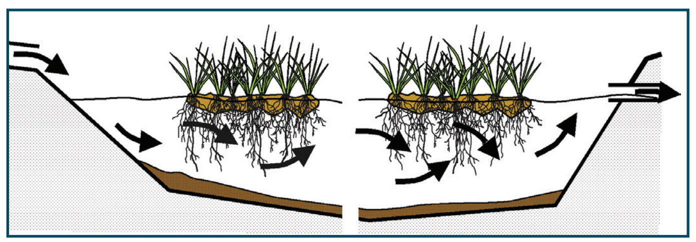

Figure 1 - Schematic longitudinal cross-section through a typical Floating Treatment Wetland system. Note that the water depth can vary appreciably in such a system without affecting plant growth. (Source: Headley and Tanner, 2006)

This paper summarises a series of mesocosm experiments examining the effectiveness of floating wetlands for removal of Cu, Zn and fine particulates from stormwater. A commercially available floating polyester matrix with a high surface area was used to create the FTWs. The specific objectives of the experiments were:

- to determine the rate of turbidity, Cu and Zn removal from stormwater by the floating wetland mesocosms;

Figure 2 – Six of the 12 mesocosm tanks used in the batch experiments

- to identify which components of the FTW (floating matrix, plants, soil) were most important for fine particulate, Cu and Zn removal; *and*
- to compare the performance of floating wetlands planted with four different native species.

Methods

Twelve mesocosm tanks (1m wide x 1m long x 0.75m water depth; operational water volume 0.7m3) set up under a clear plastic covered shelter were used to conduct a series of batch experiments at the Ruakura Research Centre in Hamilton during March and April of 2007 (see Figure 2). To determine the effect of different components of the floating wetlands, water quality responses were compared in triplicate for eight different 'treatments':

- a control with an equivalent area of shade provided by a black polythene cover suspended above the water surface
- the floating matrix on its own
- the matrix with growth media added
- the matrix with growth media plus artificial roots, and
- the matrix with growth media and four different plant species (see Table 1).

Treatment	Code
Control (no floating matrix, but equivalent shading)	C
Matrix only	M
Matrix + soil media	MS
Matrix + soil media + Artificial Roots	AR
Matrix + soil + *Carex virgata*	CV
Matrix + soil + *Cyperus ustilatis*	CU
Matrix + soil + *Juncus edgariae*	JE
Matrix + soil + *Schoenoplectus tabernaemontani*	ST

Table 1 – Summary of experimental treatments compared

The experimental floating wetlands comprised 0.36m2 squares of polyester fibre matrix injected with polystyrene foam to provide buoyancy (BioHavenTM, Floating Islands International, Shepherd, Montana). The buoyant matrix was 150mm thick on the edges with a 50mm depression in the top layer to hold the growth media (one part sand, two parts peat, one part compost). Four different plant species were compared (the best of six species tested in preliminary trials) which had been grown on a synthetic stormwater solution for 10 months prior to the experiments. The unvegetated matrix treatments were also pre-conditioned in the same synthetic stormwater solution. The synthetic root systems were made using polyester threads with a root-like structure and similar length and density to that of the roots under the planted matrices.

Each treatment was monitored during two batches of seven days, with some batches being continued for 14 days. The mesocosms were loaded with a fresh batch of artificial stormwater on Day 0 and then emptied at the end of the batch period. The synthetic stormwater was adjusted to have an initial concentration of key elements as shown in Table 2, which are similar to the mean of the 90th percentile concentrations reported by Timperley and Reed

	Dissolved Cu	Dissolved Zn	NH_4-N	NO_3-N	TDP
Mean of the 90th percentile concentration (mg/m^3)	16	485	300	3000	100
Nutrient salt added	$CuSO_4.5H_2O$	$ZnSO_4.7H_20$	NH_4NO_3	KNO_3	KH_2PO_4

Note: TDP = Total Dissolved Phosphate

Table 2 – Target concentrations of key elements in the artificial stormwater

(2004) from a two year monitoring programme of stormwater from eight different catchments in Auckland City. A commercially available hydroponic fertiliser was also added in small quantities to provide a background mix of other nutrients and trace elements (P, K, Ca, Mg, Fe, Mn, SO4, B and Mo). The mesocosm tanks were cleaned in between each batch to remove any sediment or biofilm that had accumulated during the preceding batch.

During the second batch of each of the treatments, kaolin (a white, ultra-fine ⇠0.6micron china clay) was added to the stormwater solution at a rate of approximately 160g per mesocosm (ff200 gm-3) in order to simulate the fine suspended particulate load that typically remains in stormwater following primary sedimentation. The kaolin was added to the artificial stormwater mixing tank and gently mixed using a small pump for approximately 24 hours prior to filling, so that the artificial stormwater contained a suspension of only the poorly settleable, very fine particulate fraction. Depth averaged water samples were collected from the mesocosms on days 0, 1, 3 and 7 of each batch and analysed for dissolved and total Cu and Zn. Turbidity and a range of other physio-chemical parameters water samples were measured 20cm from the surface and 20cm from the bottom of the tanks. A suite of plant biomass measurements were made at the end of the trials.

Results and discussion

Plant growth

The four native New Zealand plant species used in the experiments showed excellent growth in the floating mats, with extensive development of roots beneath the water (Figure 3). The average

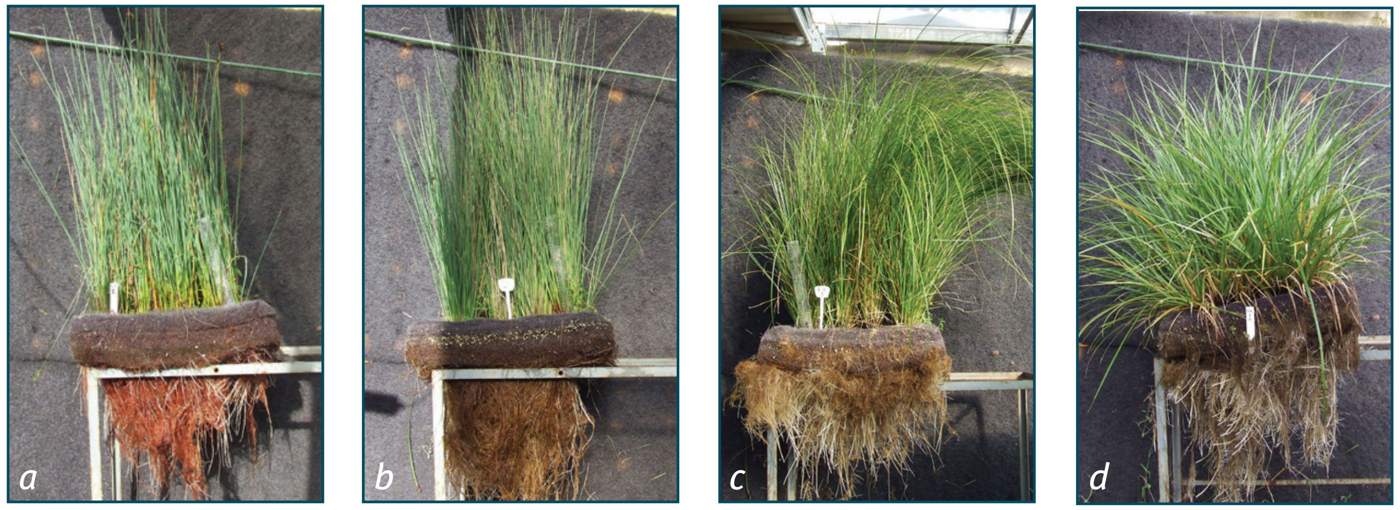

Figure 3 – Representative examples of aerial and submerged plant biomass in the planted floating mats after one year's culture in synthetic stormwater: a. Schoenoplectus tabernaemontani; b. Juncus edgariae; c. Carex virgata; d. Cyperus ustilatus. The dimensions of the square floating mats are 60x60cm, with a depth of 15cm

depth of growth of roots for the four test species was between 24cm and 48cm below the mat, with maximum depths of up to 87cm recorded for Juncus edgariae. Average above-mat dry weight biomass of 834–2350gm2 and root biomass of 184–533 gm2 (both highest for Carex virgata) were recorded after a year's growth with average species above:below-mat biomass ratios between 3.7 and 4.5.

Water quality enhancement

A selection of the results from the batch loaded mesocosm trials are summarised here; full results are available in Headley and Tanner (2007). Practically all the metals added in the synthetic stormwater remained in dissolved form during the course of the experiments. As there was negligible difference between dissolved and total metal concentrations, only the total concentrations are presented. Except for turbidity measurements, the data from the two repeated batches for each of the treatments (with and without kaolin addition) have been grouped together. Because negligible adsorption of metals to the kaolin occurred, loss rates were very similar with and without kaolin. Due to slight variations between batches in the starting concentration of some parameters, the concentration data has generally been normalised by dividing by the initial concentration (Cin) to enable direct comparison. Hence, graphs depict the proportion of the initial concentration that remains in the water at time = t since the start of the batch (Ct/Cin).

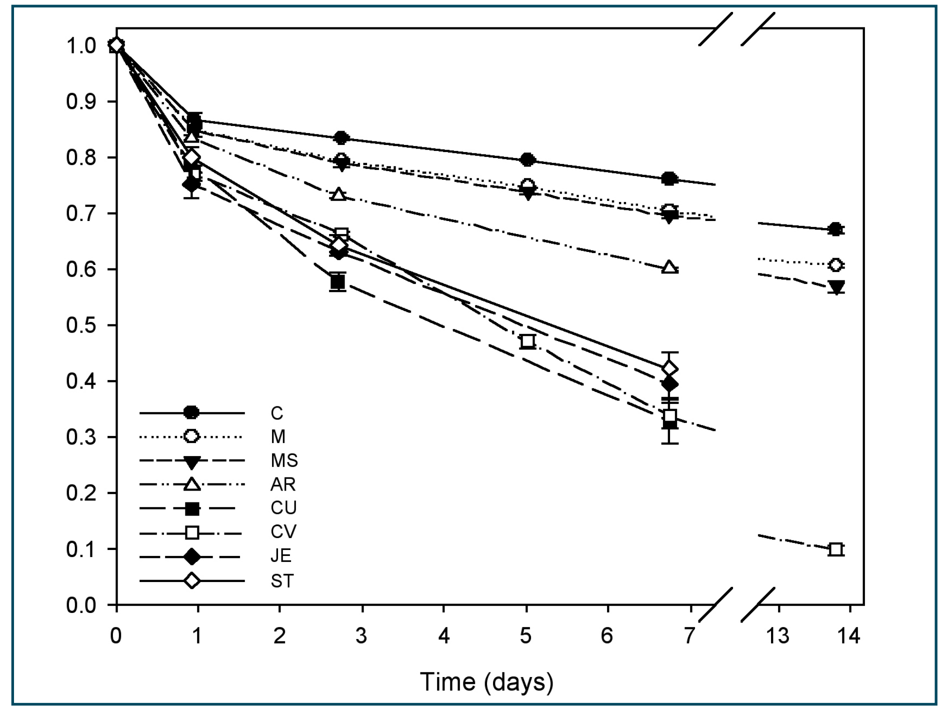

Figure 4 – Mean proportion of Turbidity remaining (C/Cin) at 20cm from the bottom of the tanks for each treatment (n=3). Initial concentrations (Cin) were 10.2NTU. Error bars (not always visible) represent ± one standard error of the mean. Note that 14 day samples were only collected for some treatments (AR, CU, JE and ST) during one batch

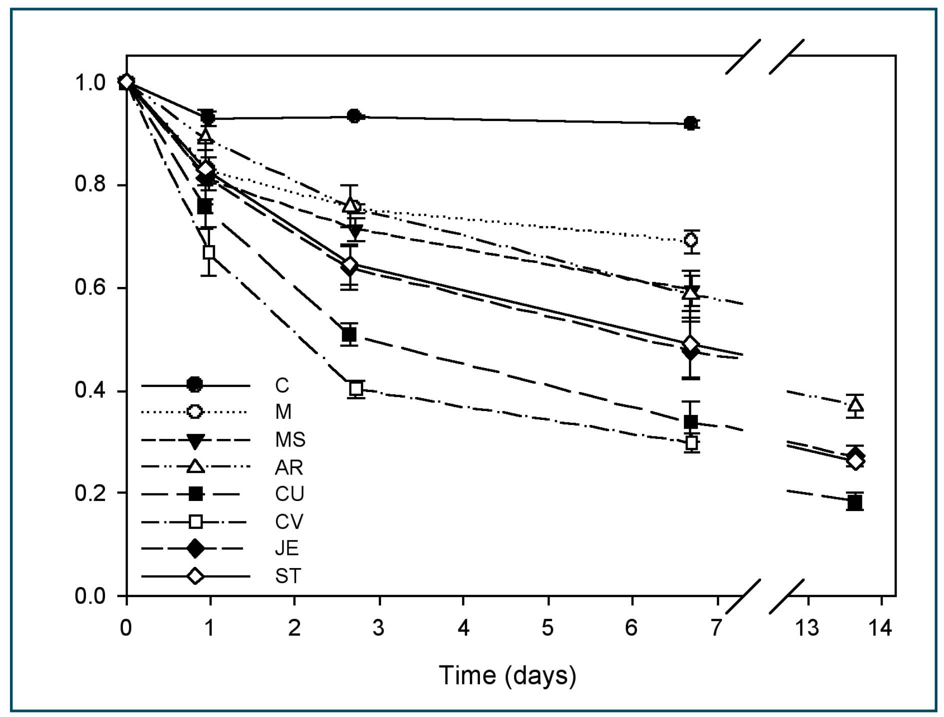

Figure 5 – Mean proportion of Total Cu concentration remaining (C/Cin) for each treatment (n=6). Initial concentrations (Cin) ranged from 0.010 to 0.01 gm-3. Note that 14 day samples were only collected for some treatments (AR, CU, JE and ST) during one batch (n=3)

As seen in Figure 4, the planted floating wetlands were the most effective at reducing the turbidity of the stormwater solution (57–67% reduction after seven days), followed by the floating matrices with synthetic roots (36% reduction after seven days). The turbidity reductions in the Matrix and Matrix+Soil treatments (30% reduction after seven days) were only slightly better than the Controls (23% reduction after seven days). These results suggest that the installation of a planted floating wetland on a pond should improve the removal of fine suspended sediments (and any associated metals).

The planted floating wetlands achieved the greatest reduction in total Cu concentrations (65–75% after seven days from initial concentrations of 10–17 mgm-3; see Figure 5), followed by the Synthetic Root treatment (50% after seven days). The Matrix+Soil and Matrix treatments achieved an intermediate degree of total Cu removal (43% and 30% reductions after seven days respectively), suggesting that the surface area provided by the Matrix plays some role in Cu removal. There was essentially no change in the total Cu concentrations in the control treatments over the seven day batch.

The results for total zinc were less clear (data not presented), with less than 40% concentration reductions achieved by all treatments after 7 days (initial concentrations 0.44–0.53gm-3). All of the treatments with Matrix included removed more Zn than the Controls. The Matrix+Soil treatment achieved the greatest reduction of total Zn, followed by the Synthetic Roots and matrices planted with Cyperus ustilatus, which is challenging to explain.

Conclusions

This study has provided encouraging results that support the potential application of FTWs for removal of Cu, Zn and fine suspended particulates from urban stormwater. The presence of living plants played a key role in the removal of Cu and fine suspended sediments. However, the role of plants in Zn removal is less clear. The results indicate that FTWs are capable of achieving dissolved Cu and Zn mass removal rates in the order of 3.8–6.4 mgm-2d-1 and 25–88 mgm-2d-1 respectively, which compare favourably to removal rates reported for conventional surface flow and subsurface flow constructed wetlands at similar loading rates. Although not directly measured in the present study, the removal of particulate-bound metals is also likely to be high given that the FTWs removed approximately one third of the very fine suspended particulate load within three days. The results support the need for further studies to investigate long term treatment performance under field conditions.

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References

Auckland Regional Council, 2004. Management and Treatment of Stormwater Quality Effects in Estuarine Areas. ARC Technical Publication No. 237, Auckland Regional Council, Auckland.

Griffiths G. and Timperley M., 2005. Auckland City Stormwater – a summary of NIWA and other relevant studies. NIWA Client Report AKL2005-007 for Metrowater Ltd, Auckland (Oct 2005).

Headley T. R. and Tanner C. C., 2006. Application of Floating Wetlands for Enhanced Stormwater Treatment: A Review. ARC Technical Publication No. 324, Auckland Regional Council, Auckland (Nov 2006).

Headley T. R., and Tanner C. C., 2007. Floating wetlands for stormwater treatment: removal of copper, zinc and fine particulates. ARC Technical Publication, Auckland Regional Council, Auckland, (Nov 2007).

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Modelling the Opanuku-Oratia streams: Lessons learnt

By Habib Ahsan, GHD Limited, and Ranjit Ranatunga, Waitakere City Council

The Opanuku-Oratia Streams Catchment covers a total land area of some 6,000ha and has its headwaters located on the eastern and southern slopes of the Waitakere Ranges. For many years, flooding has been a hazard in the lower reaches of both the Opanuku and Oratia Streams.

GHD was commissioned by Waitakere City Council (WCC) to undertake a study aimed at developing an integrated model for the Opanuku/Oratia Streams Catchment. The study provided an accurate assessment of floodplains in the area, and a model by which to formulate upgrade requirements designed to contain flows from various ARI (Average Recurrence Interval) rainfall events. The study also looked at why numerous modelling studies undertaken in this catchment since 1986 had not resulted in realistic outcomes. The 'lessons learnt' may assist other catchment management practitioners to complete studies resulting in realistic outcomes.

Project scope

The study area encompasses the entire Opanuku-Oratia Streams Catchment, including all tributaries of the Oratia and Waikumete streams to the south, the tributaries of the upper Opanuku stream to the west, and the middle and lower reaches of the Opanuku stream to the north, downstream from a bridge on the North Western Motorway (State Highway 16) – see Figure 1.

GHD developed an integrated hydrological and hydraulic MIKE11 model of the entire Oratia-Opanuku Streams Catchment extending upstream from the motorway bridge. The stream network comprises approximately 272 newly surveyed cross-sections, and about 72 cross-sections from the previous model. The catchment area has been divided into 284 subcatchments assigned to the stream network.

Project methodology

Key aspects of the Opanuku-Oratia Streams Catchment Study were:

- Subcatchment delineation
- Imperviousness estimation for ED and MPD
- Hydrological model development using Model B of MIKE11
- Hydraulic model development
- Model calibration
- Floodplain mapping
- Impact Assessment and
- Option analysis.

Subcatchment delineation

The hydrological component of the model is represented as 284 subcatchments. The subcatchment delineation principally involved the use of aerial photographs (taken in 2002), available contour plans, and District Plan designations. Several site walkovers were conducted, resulting in subcatchment boundaries being refined and the identification of survey requirements. Major overland flowpaths and asset data information, such as bridges and culverts, were also identified for survey during site walkovers.

Imperviousness

The Existing Development (ED) imperviousness area was estimated using the imperviousness shape files, while the Maximum Probable Development (MPD) imperviousness was based on WCC's District Plan allowances. The subcatchment imperviousness was undertaken as a GIS integration of the subcatchment boundary and the impervious surface shape file.