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PLANTER BOX RAINGARDEN FOR ZINC REMOVAL FROM STORM WATER

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Urbanization creates problems for the natural water systems, such as an increase in run-off volume due to the impervious surfaces and a negative impact on groundwater recharge. These changes and exposure to contaminants such as suspended/dissolved solids and heavy metals severely degrade stormwater quality. In Christchurch, heavy metals such as zinc found in run-off, which is mainly sourced from galvanized roofing. The main idea of this research is to solve run-off issues at the source, along with the construction phase. This idea is aligned with the NZ's Unitary Plan to keep rainwater run-off after a new development equal or less than the run-off that occurred before the development. Different methods of treatment for roof run-off were evaluated in this research to propose a sustainable solution followed by an assessment. A multi-layered planter box raingarden was selected since it helps to landscape, improve water quality, and perform as an attenuation device. The research concentrated on maximizing water quality while maintaining a required flowrate. The planter box raingarden performed at a low vertical hydraulic conductivity rate of 164 mm/hr and achieved a high removal rate for heavy metals. The removal rate for dissolved zinc and total zinc was 99.7% and 99.1%, respectively. The results explained that the planter box raingarden performs well as an attenuation device while adsorb and filter contaminants remarkably.

Keywords: Storm water attenuation, Roof materials, Run-off pollutants, Dissolved zinc.

1 INTRODUCTION

Globally and locally, urban areas are growing and will continue to do so. By 2050 the amount of the world's population living in urban environments is expected to be 70% (Li *et al.* 2018). Urbanization causes a range of negative water-related environmental issues, mostly caused by run-off. This is largely due to increased run-off quantity, changes in run-off speed, and increase in run-off travel distance. Contaminant sources in run-off are caused by the type of materials used to construct roads, sidewalks, roofs, etc. Urban environments are largely constructed with impervious materials, which do not allow water infiltration. These impervious materials range in coverage from 20% in residential zones up to 85% in commercial/industrial zones (Dietz and Clausen 2004). Impermeable paved surfaces and roofs increase the amount of run-off leaving an area. Providing longer travel distances allows larger carrying capacity and time for pollutants to be dissolved and/or suspended (Haselbach *et al.* 2014).

Locally in Christchurch, all stormwater travels through and over roofs, gutters, driveways, roads, and parks and into the drain system, which will all eventually flow into streams, rivers, and the ocean. Throughout the travel path, pollutants are either produced by the surface or settled on it from another source. Ecosystems are affected by poor water quality, which can cause depletion in plant and animal life. Other effects include the contamination of drinking water sources and the ability for waterways to be used for recreational activities. Waterways are failing to meet quality standards due to pollutants from surrounding urban areas. Testing and monitoring undertaken on five river catchments in 2017 found that 20% of all samples taken failed to meet monitoring standards, with 98% of the sites not meeting at a minimum of one water health guideline. The results reflect the same findings of the previous year's results showing little to no improvement over time periods (Margetts 2014).

The overall water quality in Christchurch waterways fails to meet quality standards, these values being 1 mg/L for copper and 5 mg/L for Zinc (Australian and New Zealand Environment and Conservation Council 2000) and is largely due to the contaminants picked up in run-off during storm events. The contaminants largely exist in the form of heavy metals (mainly zinc and copper), suspended solids, and dissolved solids.

The primary issue to be addressed and investigated to improve the quality of water in Addington Brook catchment is the removal of zinc contaminants from the waterways during stormwater run-off followed by reducing the risk of flood. Addington is a major suburb located approximately 2.5 km southwest of the central Christchurch City. The catchment has an area of approximately 243 ha and is mainly populated with industries and commercial properties. Figure 1 outlines the area of the catchment and the amount of zinc produced by three different sources.

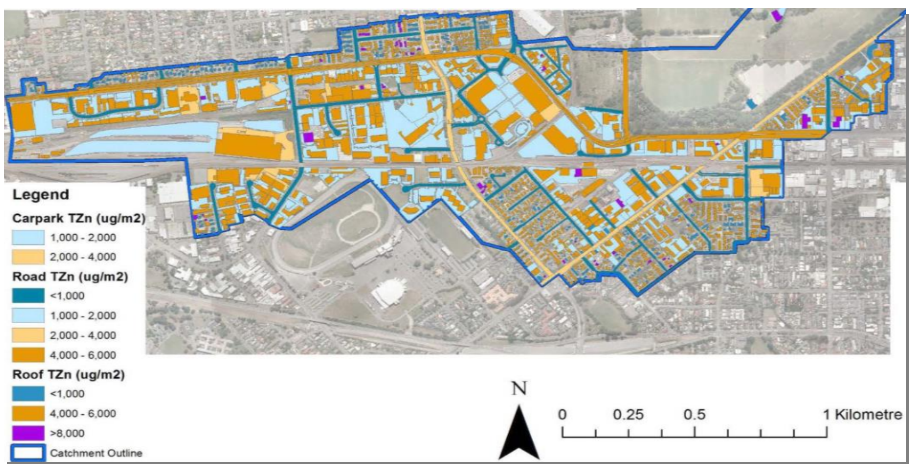

Figure 1. Addington catchment area and the produced rate of zinc from different sources (Charters 2016).

The roofing around the catchment is mostly galvanized and unpainted, which is one of the main sources of zinc contaminants. Building materials commonly exposed the elements such as roofing, guttering, downpipes, and nails are usually galvanized for its low maintenance and long lifespan. These products are more commonly used in commercial and industrial applications but can be found commonly in residential buildings. Steel and iron materials will corrode untreated, so they are often coated in a zinc layer (galvanized) for protection. Zinc oxidizes faster than steel/iron because of its lower redox potential of -0.76V, so a treated material exposed to the atmosphere creates an oxide/hydroxide protective layer. Zinc is mainly retained by adsorption and as such 94% of its concentration in run-off is usually dissolved (Bremner 2018). Hence, this research investigates, analyzes, evaluates, and recommends an appropriate site-specific stormwater treatment system for a long-term plan of enhancing the quality of water.

2 STORM WATER TREATMENT OPTIONS

Detention basins, constructed wetlands, and Ponds are highly effective in treating contaminants from various sources, such as stormwater, domestic mining, industrial wastewater, along with others. According to performance data from constructed wetland built in Baiyin City, in China, it was found that the removal efficiency for zinc contaminant was 77.6% (Si *et al.* 2014). Construction of a Wetland is not cheap due to the large area requirement. A wetland can provide living space for different wildlife and plants.

The multi-barrier treatment system is designed in a particular way so that the three diverse filtration media inside it removes various dissolved contaminants, fines solids, and heavy metals. It is generally made up of a Polyethylene mixture that has a removal efficiency of 70 % of dissolved and 76% of concentrated zinc contaminants (Athanasiadis *et al.* 2016). The system has good aesthetic appeal with its small size and steel; however, it doesn't use natural materials for treating the storm water run-off.

Adsorption has proved to be one of the useful methods for removing dissolved metal ions from the water. By the use of iron-based adsorbents, it has been proven by different researchers that heavy metals such as zinc, arsenic, cadmium, chromium, copper, and lead can be effectively removed (Stanic *et al.* 2011). This is an environmentally friendly system, as the sludge generated by the system can be reused for various purposes. The adsorption method can be integrated with filtration as a special constructed garden. A planter box raingarden can be designed using different layers of media. The National Institute of Water and Atmospheric Research (NIWA) had suggested that this design around New Zealand on average could remove 59% of dissolved zinc. The removal rate of heavy metals depends on the layer used in the planter box raingarden. Mussel shells have been shown to perform significantly well in the removal of run-off contaminates. Mussel shells dose of 6 g/kg and 24 g/kg could remove zinc contaminants by 77.6% and 99.8%, respectively. Pervious concrete has been shown to be effective in the removing heavy metals (Haselbach *et al.* 2014). Initial metal retention found in the concrete was no less than 88% for all tests, and the concentration decrease was found to be no less than 83% for both zinc and copper.

From all sources relating to the treatment of run-off researched above, the quantity of treatment media has not been tested. The depth of the media will affect the infiltration rate of the run-off through it. Finding the media depth at which it can adjust pH to an optimum level will enable the design of a multi-layered planter box to perform optimally.

3 MATERIALS AND METHODS

3.1 Planter Box

Three different filter media were used to construct lab-scale planter boxes in a 1 m high, 200 mm diameter culvert pipe. The planter boxes were named as P1, P2, and P3. Figure 2 shows the detailed design of each planter box in this research. P1 contained ART3 media, P2 contained ART3 and crushed mussels' shells, P3 contained the same media as P2 but with an additional layer of dolomite lime. The current standard filter media mix that has been approved by City Council is called ART3 media. It is typically made up of 50% coarse sand, 10% locally sourced topsoil, and 40% compost material and is an exclusive blend created by Living Earth. For the purpose of testing the treatment media, three different sources were decided, i.e., old galvanized roofing, new galvanized roofing, and artificial stormwater. Artificial samples were created to mimic regular stormwater.

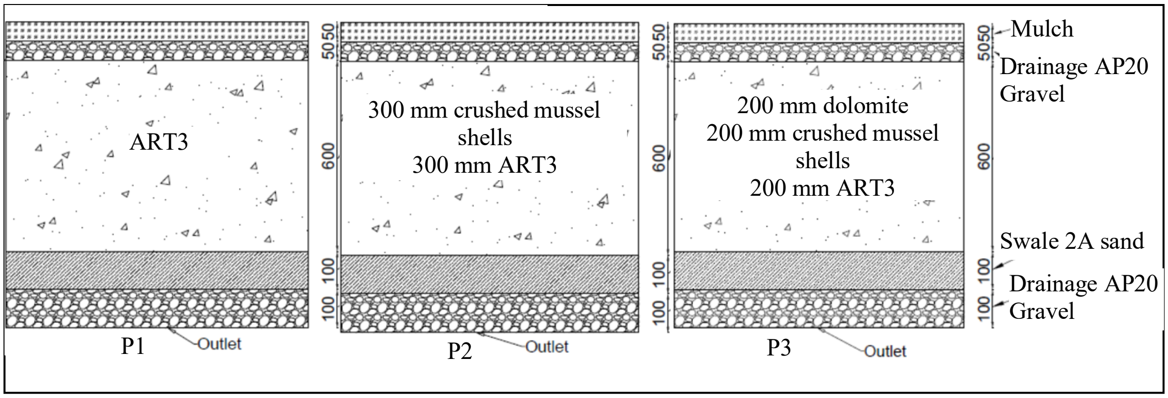

Figure 2. Three different planter box raingarden design and depth (mm) of material used in each layer.

3.2 Hydraulic Conductivity Test

Hydraulic conductivity (K) testing was undertaken using a falling head conductivity approach. The cell was used for all the media types. Tests were conducted to determine how fast the run-off would travel through each media. These values were needed to find the design depths that would allow for the required exposure time necessary to achieve an optimum pH range. The average hydraulic conductivity for each media is shown in Table 1. This average is taken from the hydraulic conductivity calculated by the three tests down with each media.

Table 1. Hydraulic Conductivity (K) of each media.

Media	K (mm/s)	Media	K (mm/s)
Sand	0.652	Gravel	1.360
Soil	0.103	Compost	0.055
Dolomite	0.157	Concrete	0.008
Mussel shells	2.186	ART3	0.037

3.3 Water Quality Test

To determine how well the designed planter box worked and to compare it to other industry projects/methods, thorough and consistent testing of the run-off quality was required. These tests undertaken consist of Total Suspendered Solids (TSS), Total Dissolved Solids (TDS), pH, Conductivity, Turbidity, Dissolved Zinc, and Total Zinc.

4 RESULTS AND DISCUSSION

The sample sources from the old galvanized roof, new galvanized roof, and artificial stormwater contained dissolved zinc between 0.69 to 2.4 mg/L and total zinc concentration between 0.83 to 3.6 mg/L. The zinc concentration in the effluent was in the range of 0.056 to 0.27 mg/L, 0.046 to 0.35 mg/L and 0.043 to 0.078 mg/L. The United States Environmental Protection Agency suggested the maximum concentration of 0.12 mg/L of zinc that depicts only P3 met the guideline. Figure 3 presents the removal efficiency of each planter box for dissolved and total zinc from different original sources. A physical adsorption process captures zinc when the stormwater sample is infiltrated the media pores. Moreover, the effect of using the crushed mussel shell media and the pH correction by dolomite is remarkable. There were essentially less than 5.3% changes in the ranges of removal efficiencies, as shown in the error bars.

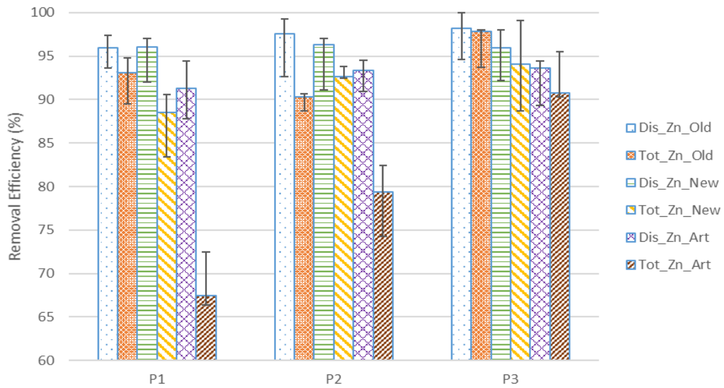

Figure 3. Total and dissolved Zinc removal efficiency of each planter box different runoff samples.

The pH test was performed on dolomite and mussel shell media to modify the depth of layers for P3 since P3 was selected as the best option considering the result for zinc removal. The depths for each layer were calculated and the new design foe filed scale study is presented in Figure 4. The only difference between the two planter boxes is the ART3 and crushed concrete layer, in order to compare the rate of sorption of dissolved heavy metals. The results showed that the dissolved zinc removal for the ART3 mixture ranges from 99.41% to 99.49%, whereas the concrete ranges from 99.60% to 99.91%. The ART3 mixture ranges from 99.01% to 99.92%, whereas the concrete ranges from 98.41% to 99.47% for the total zinc. Although the concentration of dissolved zinc is higher than the suspended zinc, it is proved that the media can remove dissolved matters more efficiently.

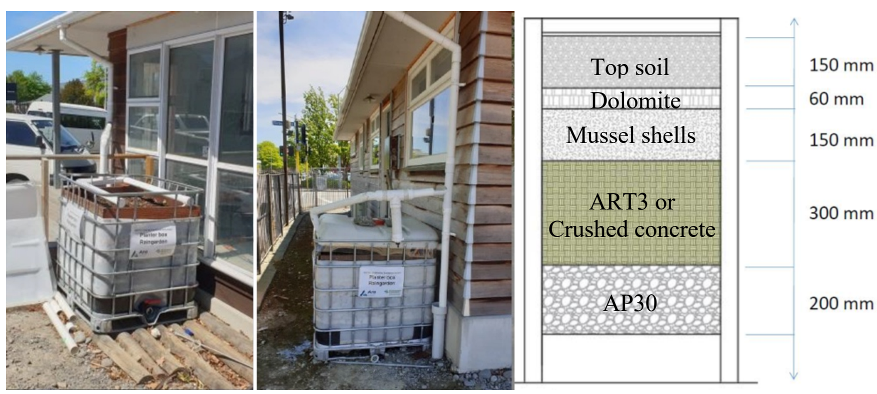

Figure 4. Planter boxes set-up and details of the layers.

The effectiveness of planter boxes against rain events was tested for unsaturated and saturated materials. This data was then plotted, as shown in Figure 5. For this test, 20 liters of water poured into the planter box at a constant rate of 3 liters per minute. This was equivalent to the worst-case scenario rainfall of 0.18 m^3/hour that was used for earlier equations. The timer was started when the water started to be added and samples of 500 ml started to be collected. As soon as 500 ml had come out, the time was taken and another sample was collected. It can be seen that the first 500 ml out of the ART 3 planter box took around three times as long as the first 500 ml out of the concrete planter box. This was the case for both the saturated and unsaturated tests.

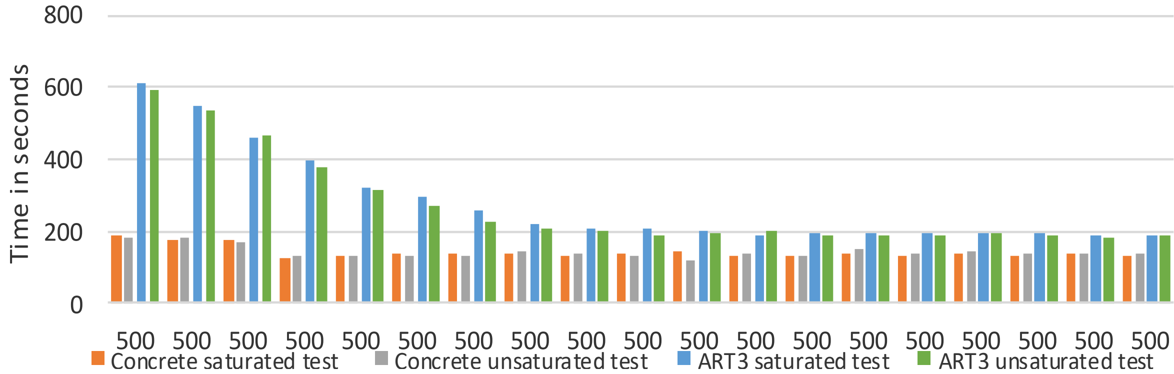

Figure 5. Time required for the collection of every 500 ml sample from each planter box.

5 CONCLUSION

In this research stormwater planter boxes effectiveness as stormwater treatment and an attenuation device are assessed. Two planter boxes were made using different treatment layers to compare and determine which treatment layer was the most effective. Both dissolved and total Zinc concrete had better overall performance in terms of removal. Both concrete and ART3 increased post-treatment values in most cases, but concrete improved its post-treatment values faster than the ART3. Conductivity tests for field-scale applications were conducted and found that the water would travel through the box in 2 hours 48 minutes, which is what was expected from the calculations.

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