MONITORING OF THE TREATMENT TRAIN AT THE ALBANY PARK N RIDE

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ABSTRACT

Operating different stormwater treatment devices in series as a treatment train may remove a wider span of pollutants and hence improve the overall performance of the system. Very few treatment trains are currently in place in Auckland region. To evaluate the effectiveness of the treatment trains, the University of Auckland and the Auckland Regional Counciis are performing a monitoring programme of a treatment train receiving urban runoff on the North Shore.

The monitoring site is a "Park and Ride" bus station located in Albany. Stormwater runoff from the parking lot and roadway runs through a series of treatment devices including rain gardens, grassed swales, a StormFilter and a constructed wetland prior to discharging to Lucas Creek. Field monitoring stations were set up for each component of the treatment train. Data were collected and analyzed for hydrologic and water quality assessment. Event mean concentrations of total suspended solids, total dissolved solids, total and dissolved zinc, total and dissolved copper show the site is very clean compared to most urban runoff. The treatment train is effective at water quality control except for total dissolved solids removal. Results to date are presented, including data from at least 4 storms from each station.

KEYWORDS

Treatment train, stormwater management, water quality assessment

PRESENTER PROFILE

Mingyang (Mona) Liao recently submitted her Master's thesis in Civil and Environmental Engineering at the University of Auckland on the topic of the current paper. Mona completed her Bachelor of Civil Engineering (Hons) at the University of Auckland in 2007.

1 INTRODUCTION

The Auckland metropolitan area has grown into the largest city in New Zealand over the past 150 years. It is estimated that the population in the Auckland region will be over 2 million and the metropolitan area will expand to around 60,000 ha by 2050 (ARC, 2004b). The increasing development and urban activities add pressures to the natural environment alter the hydrologic regime and degrade the quality of Auckland's waterways. Environmental monitoring programs indicate that stormwater runoff carries a wide range of pollutants and has the single largest impacts on the region's marine and estuarine environments (ARC, 2004a, Greenway et al., 2002, PGDER, 1999). Potential stormwater contaminants include litter, trash, sediments, organic mater, bacteria, chlorides, heavy metals, oil and grease, and nutrients (ARC, 2003, Brodie, 2007).

The customary approach to stormwater management locally is to use devices, also known as the structural best management practices (BMPs), BMPs are usually designed to be multifunctional, which can reduce hydrologic impact, remove contaminants from stormwater and enhance the environment at the same time (Villarreal et al., 2004). Stormwater BMPs typically used in Auckland are classified as detention practices such as ponds and tanks, vegetative practices such as swales and rain gardens, and filtration practices such as sand filters. The general contaminant removal processes include sedimentation, aerobic and anaerobic decomposition, filtration and adsorption to filter material, biologic uptake, and biofiltration (ARC, 2003). It is assumed that most contaminants adsorb to suspended solids, hence removal of sediments can remove most of the contaminants. Coarse suspended solids can be captured by treatment devices or deposited in catchpits by sedimentation. However, other contaminants tend to bond to silt or finer particles that do not settle easily. Dissolved contaminants and hydrocarbons also require other removal mechanisms. To achieve higher performance standard and to address a larger suite of pollutants, a complex combination of processes is usually required.

Although there is a wide range of stormwater treatment devices "acceptable" by local regulation, there are constraints such as space, soil type and slope that can affect the applicability of a specific BMP under specific context. For example, rain gardens are generally suitable for residential developments, road median or traffic islands in parking lots with relative small drainage area (less than 1 ha). Most of the rain gardens in Auckland cannot easily promote infiltration due to predominance of clay soils. The use of swales and sand filters are also limited to small catchment areas. Constructed wetlands can remove a wide range of pollutants; but like other ponds, they are more appropriate for larger catchment areas and can not be used in areas with steep slope or sandy soil.

In addition, the contaminants removal potential varies with individual BMP. According to the performance recorded in the International Stormwater BMP Database (www.bmpdatabase.org), BMPs such as retention pond/wet ponds and wetlands can provide extended storage for stormwater runoff; therefore achieve lower effluent total suspended solids (TSS) concentrations on average compared with other types of BMPs. Biofilters show the greatest metal removal capability especially for metals in dissolved form. Detention pond effluent has much lower total metal EMCs compared to influent but does not show significant reduction in dissolved metals. Hydrodynamic devices are not effective at removing dissolved metals.

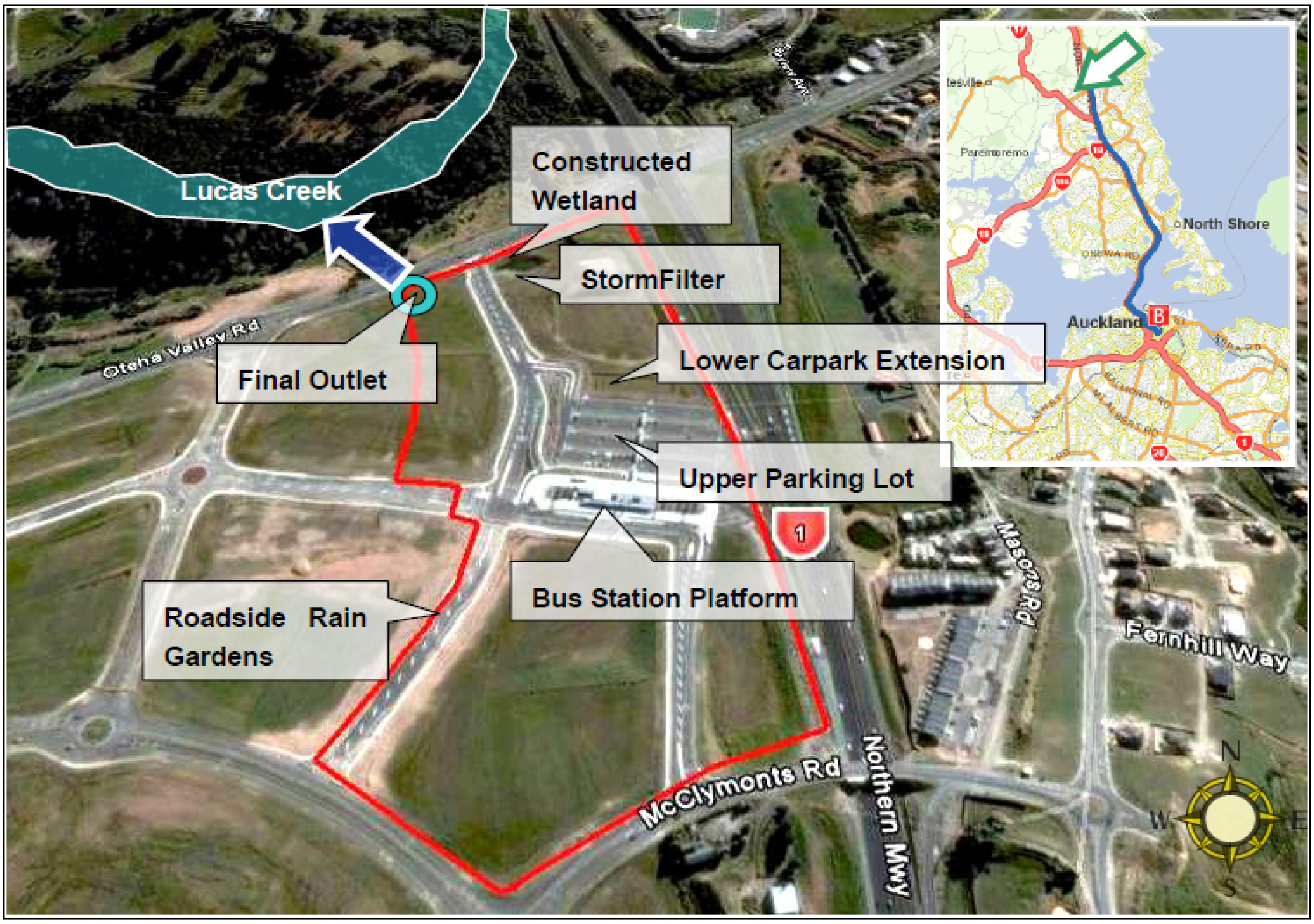
Operating different stormwater treatment devices in series as a treatment train can theoretically provide a wider span of pollutant removal capability and spread the hydrologic controls throughout the site thus improve effectiveness of the overall site stormwater management (Barr Engineering Co.). The ARC encourages using the treatment train approach for stormwater management in any site development (ARC, 2003). But very few treatment trains have been implemented in the Auckland region. Although there have been studies on various BMPs world wide, there is a lack of information and case studies on effectiveness of treatment trains (Villarreal et al., 2004). To evaluate the performance of treatment trains under the local context, a monitoring programme of a treatment train receiving urban runoff in the Auckland region supported by the ARC was launched in late 2007 with an initial study period of 1.5 years proposed.

2 METHODOOGY

2.1 SITE DESCRIPTION

The selected monitoring site is the "Albany Park & Ride" located southwest of the intersection of the Oteha Valley Road and the north bound off ramp of the Northern Motorway SH1 (Figure 1). The Albany bus station opened in Nov 2005 and is the first phase of the Northern Busway project that connects North Shore and the central Auckland (Northern Busway). It is the first park and ride bus station in New Zealand, with 430 commuter parking spaces and heavy bus traffic. The car parks have been regularly full since its opening. The expansion of the car park in early 2007 added another 180 parking spaces to meet the demand (North Shore City Council, 2007). A series of stormwater treatment devices were installed on site to manage the runoff from the bus station platform, roading infrastructure, car park facilities and surrounding grassy area. The total catchment area is approximately 14.7 ha with around 43% impervious area. The catchment has a clay type soil that falls in class C of the SCS hydrologic soil groups. Discharge of treated stormwater effluent from the treatment train system enters Lucas Creek through the stormwater sewer network at the downstream end of the catchment.

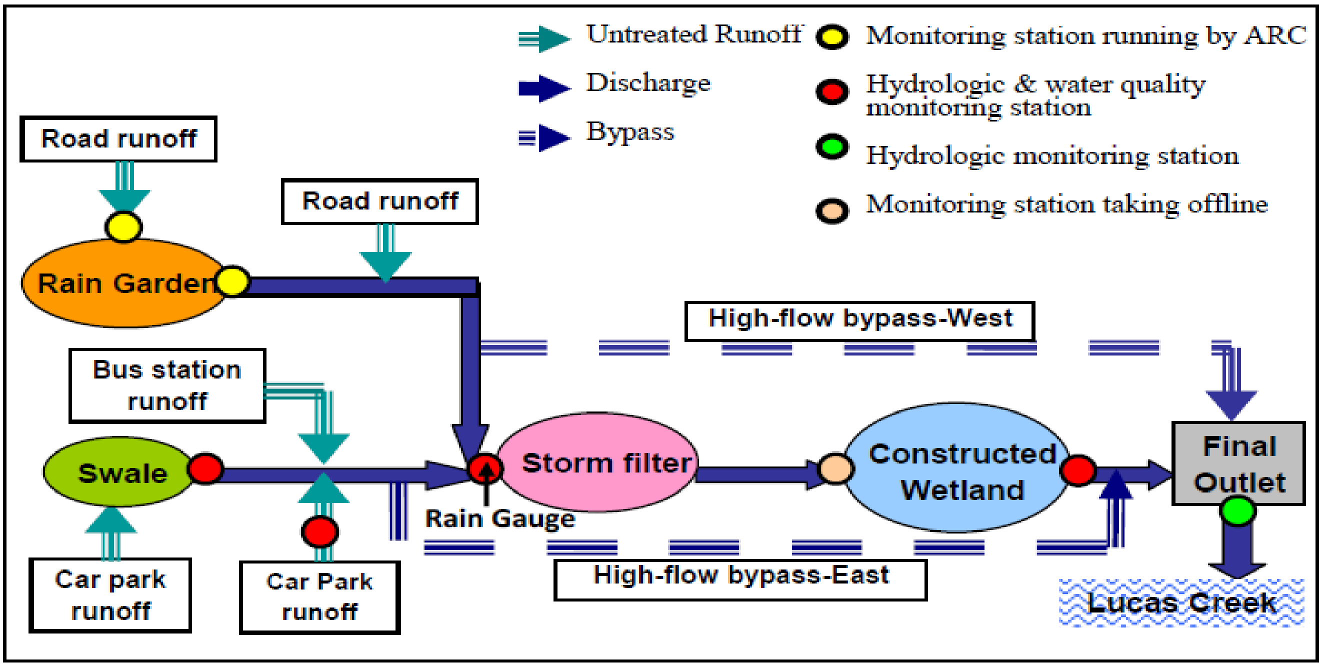
Figure 1: Albany Park & Ride Catchment Area and Location (Google Maps, 2008)



* Red line represents the drainage area; **Aerial photo reproduced from Google Maps, the latest update in 2006 which was before construction of many of the site features including the lower car park extension.

Stormwater treatment devices installed at the Albany bus station from upstream (south) to downstream (north) include four rain gardens along the road side at the southwest end, two sets of parallel grassed swales in the upper parking lot and lower car park extension, an underground StormFilter and a constructed wetland at the northern end. Figure 2 below shows a simplified flow schematic of the treatment train. Runoff collected by catchpit is pre-treated with a cesspit filter system know as the Enviropod. There are 70 Enviropods installed in the catchment. As the Enviropod is designed to capture large particles such as litter, debris, rock, vegetative clippings and coarse sand, it is assumed that the Enviropod does not have major influence to pollutants in smaller size. Stormwater runoff from the catchment drains to the treatment systems via two parallel routes located to the west and east of the bus station. The upper car parks on the east side of the site drain to seven swales with an Enviropod installed at each of the swale outlet catchpits. The lower swale system in the car park extension includes three parallel swales that are connected via underground pipes. All the upper swales and the lower swales are hydraulically connected to a single discharge point by a subsurface pipe network and are routed to the StormFilter located further downstream.

Figure 2: Treatment Train Flow Schematic



The rain gardens along the road to the west of the bus station provide treatment to the roadway runoff and drain to the StormFilter through a storm sewer on the west side. Effluent from rain gardens and swales is directed into the StormFilter via two stormwater splitter manhole chambers with high flow bypass to the final outlet. After passing through the StormFilter, runoff drains to the constructed wetland and then discharges to the final outlet, where all the flows converge to enter the receiving water of Lucas Creek to the north of Oteha Valley Road. The primary focus of the work presented in this paper is on the eastern route of the treatment train i.e. the swale, StormFilter and constructed wetland system (Figure 3-5).

All the grassed swales are designed and constructed in the same profile with a trapezoidal cross section, 1.0 m base width, 200 mm depth, 3.3 m/m H:V side slope, and 3% longitudinal slope. The longitudinal lengths of swales vary from the shortest of 30 m in the upper swale system to longest of 90 m of the most downstream swale in the lower swale system.

According to information provided by Stormwater 360, the StormFilter installed at the Albany bus station contains 148 ZPG (mixture of zeolite, perlite and granular activated carbon) filter cartridges in an underground chamber which is approximately 15.5 m long by 4.4 m wide with an invert level of 2.5 m. It has been sized based on the design storm for water quality with a peak flow rate of 141 L/s. The total catchment area served by the StormFilter is 14.7 ha, of which 69.5% is on the eastern route. The StormFilter outlet is directly connected to the wetland inlet via a short pipe of 7.6 m.

The constructed wetland immediate after the StormFilter is 37 m long by 13 m wide. The surface area is approximately 390 m^2 at the permanent water level. There are two outlet structures; one is the service outlet of an 80 mm diameter inverted siphon, and the other is the emergency outlet of a timber post and rail broad-crested rectangular weir. The rectangular weir is 3.6 m wide, 600 mm deep and 600 mm above the siphon. A trapezoidal open channel followed by an 825 mm diameter pipe has been built at the downstream end of the wetland outlet. The open channel has a base width of 1.6 m, height of 1.2 m and is lined with riprap. The total length of the open channel and pipe is around 10 m.

Figure 3: Grassed Swales # 1, 2 and 3 in the Lower Car Park Extension (red area= drainage area to swale #1, blue area= drainage area to swale #2)

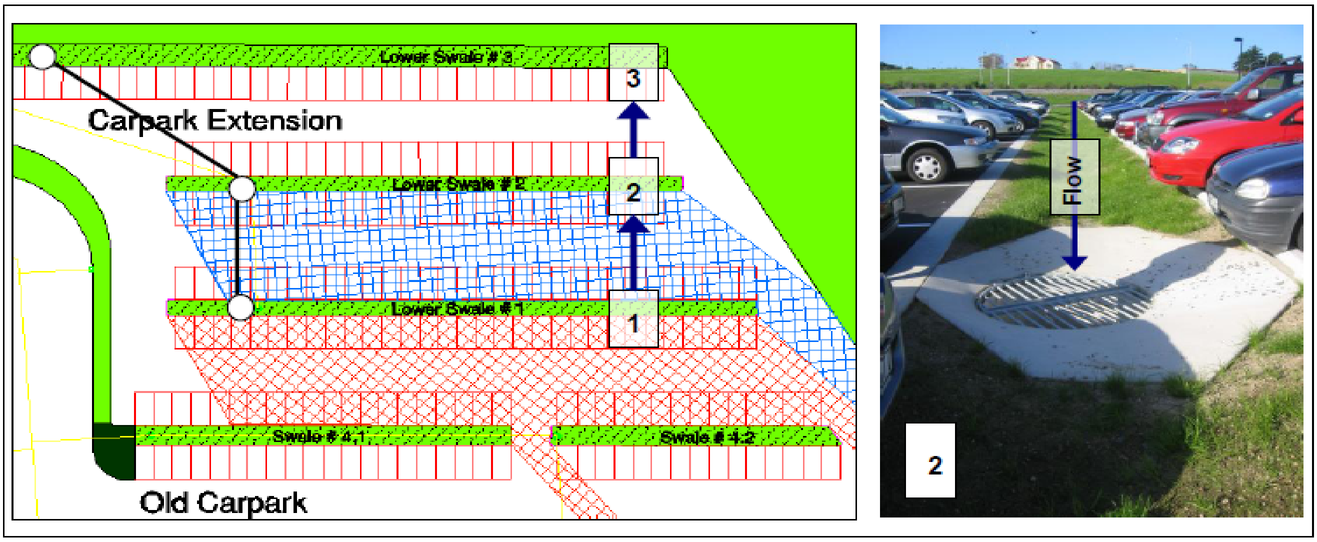


Figure 4: General Arrangements of the StormFilter at Albany Park & Ride (Connel Wagner Ltd, 2007, Stormwater360)

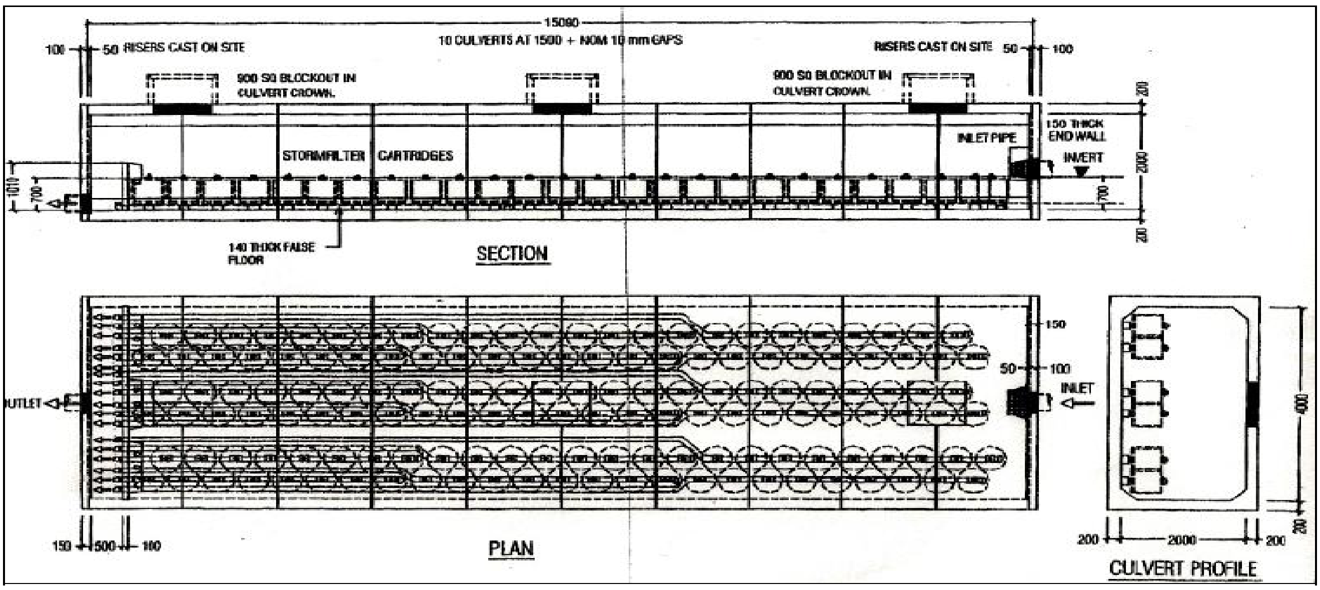


Figure 5: The Constructed Wetland

2.2 FIELD MONITORING

To assess performance of individual treatment devices as well as the treatment train as a whole, six monitoring stations were setup along the eastern route of the treatment train. As shown in Figure 2, there are five hydrologic and water quality sampling stations: the catchpit collecting untreated runoff, outlet of swale # 2 in the lower swale system, StormFilter inlet, wetland inlet and outlet, and one flow-only monitoring station at the final outlet. To assess overall site stormwater control, it is assumed that the data collected at the untreated runoff monitoring station is representative of untreated runoff throughout the treatment train and the swale discharge is representative of all swale discharges. However, initial monitoring of the wetland inlet was compromised by backwater effects. The monitoring station was taken off-line and StormFilter and wetland were then considered as one treatment system. Excessive vegetation growth at the wetland outlet downstream channel caused substantial ponding and influenced wetland operation as well as flow monitoring. Additional water level monitoring equipment was installed at the downstream channel to verify the actual operation head of the wetland outlet. In addition, substantial turbulence caused by massive flow through the final outlet and equipment complications preclude utility of data collection at the final outlet thereby compromise the treatment train system mass balance calculation at this point.

As the site condition precluded inflow measurements for the swale system, the swale peak flow reductions were only estimates based on the inflow calculated using the SCS unit-hydrograph method recommended in the *"Guidelines for Stormwater Runoff Modelling in the Auckland Region" (TP108)*.

Hydrologic data including precipitation and flow measurements were recorded continuously over eight months. Storms with a return period less than or equal to the 2 year average recurrence interval (ARI) were targeted for water quality sampling. Due to the difficulty of collecting concurrent water quality samples at four monitoring stations, the monitoring plan proposed to analyze at least 10 storms for each station regardless of whether data for entire treatment system was captured for each individual event. The intention is to generate data sets to characterize runoff at any point along the treatment train which can ultimately be combined in a statistically significant manner to determine overall site performance, even if all stations don't activate for the same events. It was hoped to capture at least six complete storm events (i.e. both hydrology and water quality data are collected at all monitoring stations for a given event).

A maximum of 24 discrete samples per storm at each sampling station were collected over the duration of the storm hydrograph at prescribed time intervals. Each sample has a volume of 1 L. Several "test" storms were monitored to determine appropriate pacing for sample collection at all the stations. Variable sampling pacing was programmed in such way that samplings occur more frequently during the rising limb of the hydrograph, and cover a period representing at least 60% of the total runoff volume of each storm event and an overall average of 75% for all the storms monitored.

SIGMA 900MAX and ISCO 6700/6712 automatic stormwater samplers were used to collect water quality samples at the four sampling points. The SIGMA sampling machine installed at the StormFilter inlet is integrated with a tipping bucket rain gauge and flow meter, which can be programmed to activate sampling based on the commencement of precipitation or when the preset water level/ flow is reached. The other three monitoring stations used the ISCO samplers that do not have the compatible accessories. Instead, a stand-alone self-logging Global Water WL 16 pressure transducer was used to measure flow depth and a float switch was added to trigger the sampling programme. Rainfall and flow data were recorded at 2 min intervals. All the sampling machines and flow loggers were synchronized, and the time was verified and adjusted during every site visit. Instrument limitations generally require >20 mm of water depth for the pressure transducer to maintain calibration and for the pump to physically be able to withdraw a sample. In order to maintain this minimum water level and enable low flow measurement, wooden V-notch weirs were installed in all the pipes at all the monitoring stations except for the wetland outlet and final outlet. Flow rating curves were established in the laboratory for the swale and StormFilter inlet using exact replicas of monitoring station configuration. A weir coefficient was laboratory calibrated for the configuration of the wetland outlet.

2.3 LABORATORY WATER QUALITY ANALYSIS

While discrete samples were collected, flow-weighted composited samples were analyzed to determine event mean concentrations (EMCs) for selected water quality parameters. Whenever possible, a minimum of 10 samples from each monitoring station were manually mixed to a 1 L composite sample according to the standard flow-weighting protocol. However, storm conditions (such as very short duration events) sometimes precluded this specification for specific events. Discrete analysis was carried out for a few "perfect" storms or when insufficient samples were collected to cover the entire storm. Flow weighting for analysis of untreated runoff was based on the hydrographs determined through SCS-unit hydrograph method.

Water quality constituents for composite analysis include TSS, total dissolved solids (TDS), pH, particle size distribution (PSD), total recoverable and dissolved zinc (Zn), and total recoverable and dissolved copper (Cu). TSS, TDS, pH and PSD were analyzed in the laboratories at the University of Auckland. Acid preserved samples were sent to Hills Laboratory for metal analysis. Temperature was recorded continuously at 2 min intervals with Global Logger in the flow stream. pH was measured in discrete samples prior to compositing. Table 1 summarizes the analytical parameters and the corresponding testing methods. Hydrocarbons were initially considered for analysis. However, as hydrocarbons float on the water surface while sediments are distributed in the deeper parts of the water column; it is difficult to collect representative samples for hydrocarbons vs. sediments. Furthermore, the poor mixing of hydrocarbons into the water column precludes mixing of composites for analysis.

All sampling bottles were washed with phosphorus free detergent Decon 90, followed by 1:1 nitric acid wash, and a final rinse of D.I. water. Samples were collected from site within 24 hours of the completion of an event and stored in the fridge under 4 ^{0}C. Holding time for TSS/TDS test was 7 days while the acid preserved samples for metal analysis were stored longer and usually sent to the Hills Laboratory within 3 weeks. For TSS/TDS testing, replicate analysis was performed on at least 20% of all the samples in each batch.

Table 1: Summary of Analytical Methods

Parameter	Testing Method Description	Units	DL*	Laboratory
Precipitation	Sigma Tipping bucket rain gauge 2149	mm/min	-	UoA
Flow	Global Water WL 16 Data Logger and Sigma pressure transducer	L/s	Flow depth > ~2cm	UoA
TSS/TDS	*Method 2540D, Standard Methods* with modifications of vigorous shaking and pouring of at least 300ml subsample	mg/L	2.5	UoA
PSD	Malvern Laser Diffraction Particle Analysis - Mastersizer 2000	µm	0.02 to 2000	UoA
pH	Eutech Instrument CyberScan pH310	pH	-2.00 to 16.00	UoA
Dissolved Cu and Zn	*APHA 3030 B, 21st ed. 2005*. Sample filtration through 0.45um membrane filter and preservation with nitric acid. *APHA 3125 B, 21st ed. 2005*. ICP-MS, trace level	µg/L	0.5 (Cu) 1.0 (Zn)	R J Hill Laboratory
Total Recoverable Cu and Zn	*US EPA 1638*. Nitric/Hydrochloric acid extraction, 85^0, 2.75 hours. *APHA 3125 B 21st ed. 2005.* ICP-MS, trace level	µg/L	0.5 (Cu) 1.0 (Zn)	R J Hill Laboratory

* DL=Detection Limit

3 RESULTS AND DISCUSSION

A wide range of storms was recorded from May 2008 to January 2009. Table 2 summarizes characteristics of precipitation for all the storm events monitored. The total rainfall depth over the monitoring period was 717.2 mm with a total of 43 events. Storms were categorized according to a typical first flush control volume of 13 mm, water quality volume (WQV) of 25 mm and the 2 year ARI rainfall depth of 85 mm. There were 25 storms smaller than the first flush volume and 2 storms greater than the

2 year storm event, with the minimum and maximum rainfall depth of 1.2 mm and 108.5 mm, respectively. Storms within the WQV range contributed to 37% of the total rainfall. Runoff occurred at all the sampling stations for all the storm events except for storms less than 2 mm, which did not produce discharge from the wetland outlet. This indicates that the site as a whole has at least 2 mm initial abstraction. The average intensity of storms ranged from 0.2 to 6.5 mm/hr, with the mean and median value of 1.5 mm/hr and 1.0 mm/hr respectively. The 10 min peak intensity was on average of 1.6 mm/hr with the highest of 25.8 mm/hr occurred during the 108.5 mm storm event and the lowest of 3.6 mm/hr occurred during the 3 mm rainfall event. Storm durations ranged from 0.2 to 48.9 hrs, with mean and median durations of 13.0 and 8.0 hrs, assuming a 3-hr inter-event time (ARC, 1999) or until there was no runoff flowing through the system from the previous storm. The average value for antecedent dry days was 2.6 days. Storm on 25/05/2008 had the longest antecedent dry days of 16.0. Storms that occurred in winter generally had greater peak intensity, longer duration and shorter antecedent dry days compared with storms in summer.

Peak flow reductions were calculated as the percentage difference between the system inflows and the outflows. Attenuation of peak flows achieved by the swales system ranged from -231 % to 83% with a mean and median of 23% and 38%. It is noted that swales had several negative values for peak flow reduction. The SCS unit-hydrograph method assumes a minimum of 10 min time of concentration. However, the swale system has a very small drainage area and short drainage path. The actual time of concentration calculated using the empirical method of TP108 was around 1.2 min. Peak flow calculated using the SCS method is likely to be underestimated for very intense storms. The physical characteristics of swales also limited their capability to control flows especially for very intense storms. Ultimately, the -230% reduction could be a statistical outlier due to the possible inaccurate substituted precipitation data. Rainfall recorded at the Oteha rain gauge station 3 km away from the monitoring site was used when the onsite rain gauge failed; there could be great variance between rainfall characteristics over the distance, especially for a small storm. The mean and median reduction would become 45% and 42% respectively with the negative values excluded.

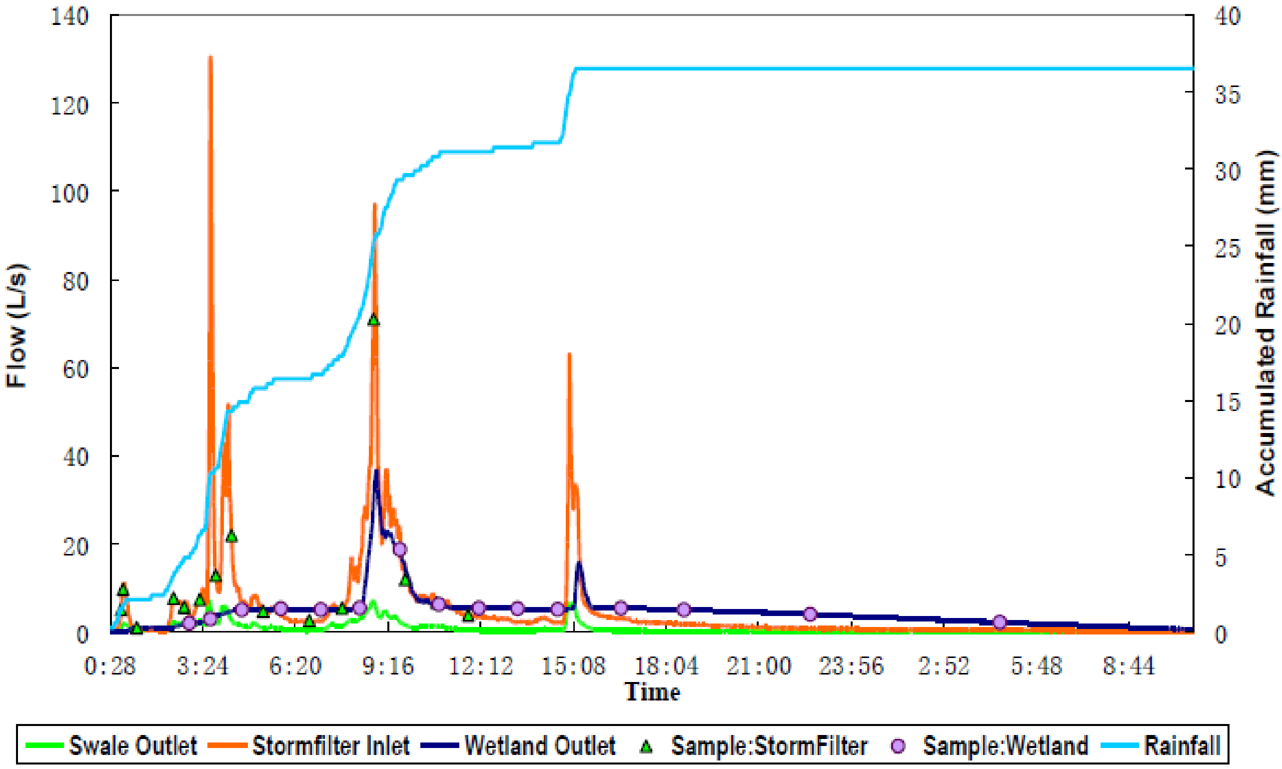
Due to the backwater effects at the wetland inlet/StormFilter outlet, individual performance of the StormFilter or the wetland could not be evaluated. The StormFilter-wetland system as a whole achieved 4% to 100% peak flow reductions with a mean and median of 77% and 87%. It was assumed that the StormFilter-wetland system had 100% peak flow reduction for minor storms (less than 2 mm) that produced runoff at all the other monitoring stations except the wetland outlet. Of the 43 storms monitored, rectangular weir flow from the wetland outlet occurred during 12 storms with higher peak intensity, shorter antecedent dry days, and greater total rainfall depths in general. As shown in Table 2, it is clear that the peak flow reduction was inversely proportional to the storm size, i.e. the treatment system had better hydrology performance for smaller, more frequent storms.

Of the 43 storm events occurred over the monitoring period, there were 19 storms successfully sampled for water quality analysis across the various stations. Overall, there were 4, 11, 7 and 6 storms tested for the untreated runoff, swale outflow, StormFilter inflow and wetland outflow, respectively. Figure 6 presents a typical example of hydrographs and discrete sample collection with variable pacing over the event durations. Individual pollutant removal performance with different components of the treatment train system is discussed in the following sections.

Table 2: Summary of Rainfall Characteristics and System Peak Flow Attenuation

Number of Events	Storm Size (mm) (Total Rainfall)	**Precipitation - Mean** (Range)				**Peak Flow Attenuation-Mean** (Range)	
		Average Intensity (mm/hr)	**10min Peak Intensity (mm/hr)**	**Storm Duration (hr)**	**Antecedent Dry Days**	**Grassed Swales**	**StormFilter-Wetland System**
25	**<13** (105.5)	**1.4** (0.2 - 6.5)	**7.3** (3.6 - 23.4)	**6.1** (0.2 - 20.6	**2.8** (0.1 - 16.0)	**33%** (-231 - 83%)	**90%** (49 - 100%)
10	**13-25** (162.5)	**1.2** (0.4 - 2.2)	**12.8** (5.4 - 25.8)	**18.9** (6.3 - 38.8)	**2.7** (0.3 - 5.9)	**15%** (-87 - 54%)	**67%** (4 - 97%)
6	**25.1-85** (243.4)	**2.0** (0.7 - 3.3)	**17.0** (9.0 - 24.6)	**21.9** (14.7 - 36.3)	**2.2** (0.3 - 6.6)	**1%** (-112 - 56%)	**55%** (37 - 72%)
2	**>85** (205.8)	**2.4** (2.2 - 2.5)	**22.2** (18.6 - 25.8)	**43.8** (38.8 - 48.9)	**1.5** (1.3 - 1.8)	**7%** (-29 - 42%)	**44%** (37 - 52%)
Summary of all events							
43	**1.2-108.5** (717.2)	**1.5** (0.2 - 6.5)	**10.6** (3.6 - 25.8)	**13.0** (0.2 - 48.9)	**2.6** (0.1 -16.0)	**23%** (-231 - 83%)	**77%** (4 - 100%)
Median	**6.9**	**1.0**	**9.0**	**8.2**	**1.0**	**38%**	**87%**

Figure 6: Hydrographs and Sample Collection: 09/12/2008



3.1 TSS AND TDS

Although data collected to date are insufficient to perform statistical analysis, the box and whisker plots still show a good representation of the distribution of pollutants throughout the system. As shown in the box and whisker plots in Figure 7, the TSS EMCs decrease as runoff flows along the treatment train, whereas the TDS EMCs have an increasing trend. Untreated runoff TSS EMCs range from 24.1 to 37.7 mg/L with mean and median EMCs of 31.6 and 32.3 mg/L. This site is really "clean" compared to most urban runoff. The untreated runoff TSS load measured is less than the average findings of other studies in the Auckland region (83.9 mg/L) (Kennedy, 2003). As a commuter parking lot, the actual traffic occurs during the day is limited. The parking lot tends to fill up early in the morning with all-day parkers. Vehicles could also act as shelters that preclude pollutants from being picked up by runoff. Runoff from the busway may have higher pollutant loads compared to the parking lot.

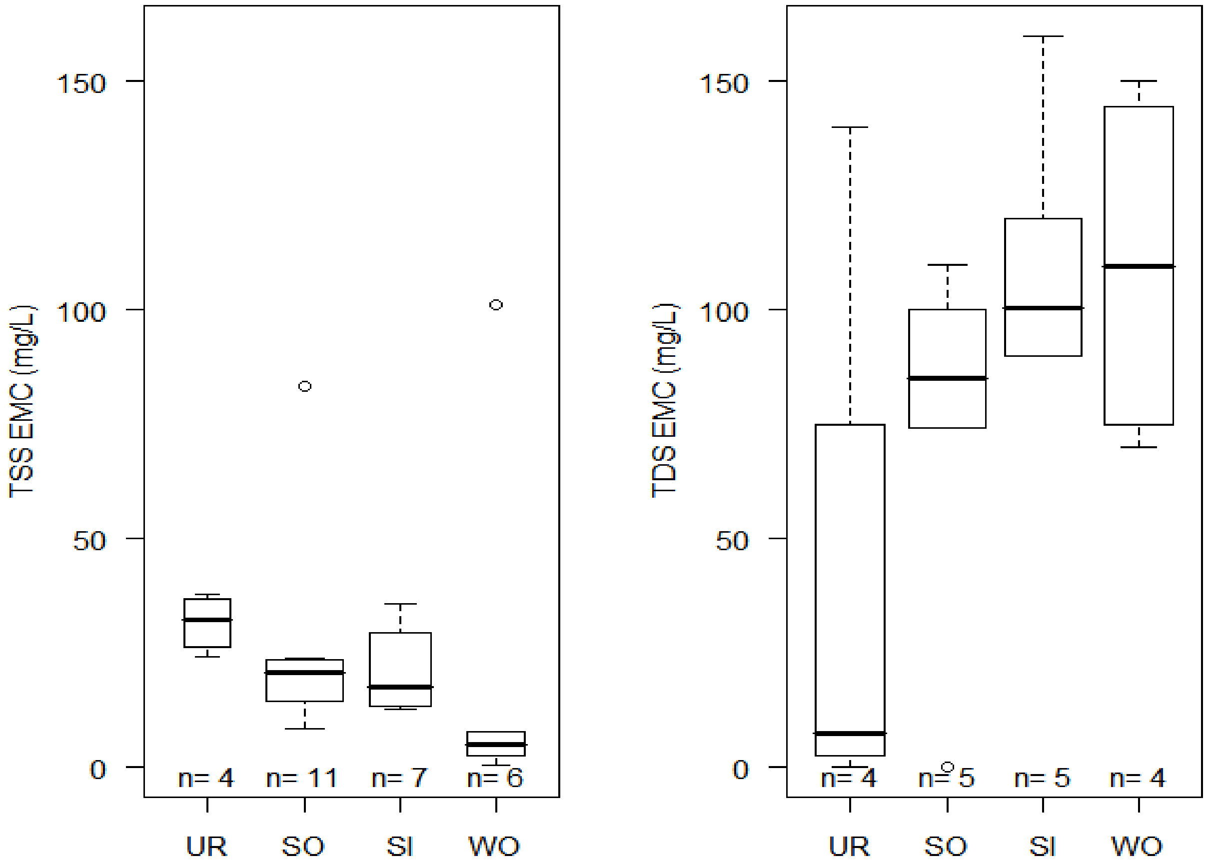
There were two statistical outliers for the TSS EMCs measured at the swale outlet (83.3 mg/L, 25/05/2008) and wetland outlet (101.2 mg/L, 09/08/2008). Storm on 25/05/2008 had the longest antecedent dry period of 16 days, for which, sediment build up could be substantial. The storm on 09/08/2008 was immediate after a series of large storms. The wetland reached its full capacity and spill flow through the rectangular weir occurred during the storm event. As shown in Figure 8, there was a substantial increase in TSS concentrations over the period of rectangular weir flow. It is likely due to the disturbance and resuspension of sediments that settled at the bottom of the pond caused by the high flow rate and reduced overall detention time.

The mean and median TSS EMC at the swale outlet were 23.5 and 20.7 mg/L, respectively, which were at the similar level compared to the average effluent EMC (23.9 mg/L) achieved by BMPs under the same category of biofilter as reported in the

International Stormwater BMP Database. Wetland outlet TSS concentrations were consistently low, excluding the outlier. Mean and median wetland outflow TSS EMCs were 20.7 and 5.1 mg/L respectively. The average wetland effluent TSS EMC was consistent with the findings reported in other studies, while the median effluent TSS EMC was well below the average level of 17.8 mg/L. Overall the treatment train shows a good ability to reduce TSS loads compared to other types of BMPs (range of median average effluent EMCs: 13.4 - 37.7 mg/L), even when inflow concentrations are already low. However, as the EMC measured at the wetland outlet was representative of the combined effects of both StormFilter and constructed wetland, it is unclear about the contribution of each component in the system.

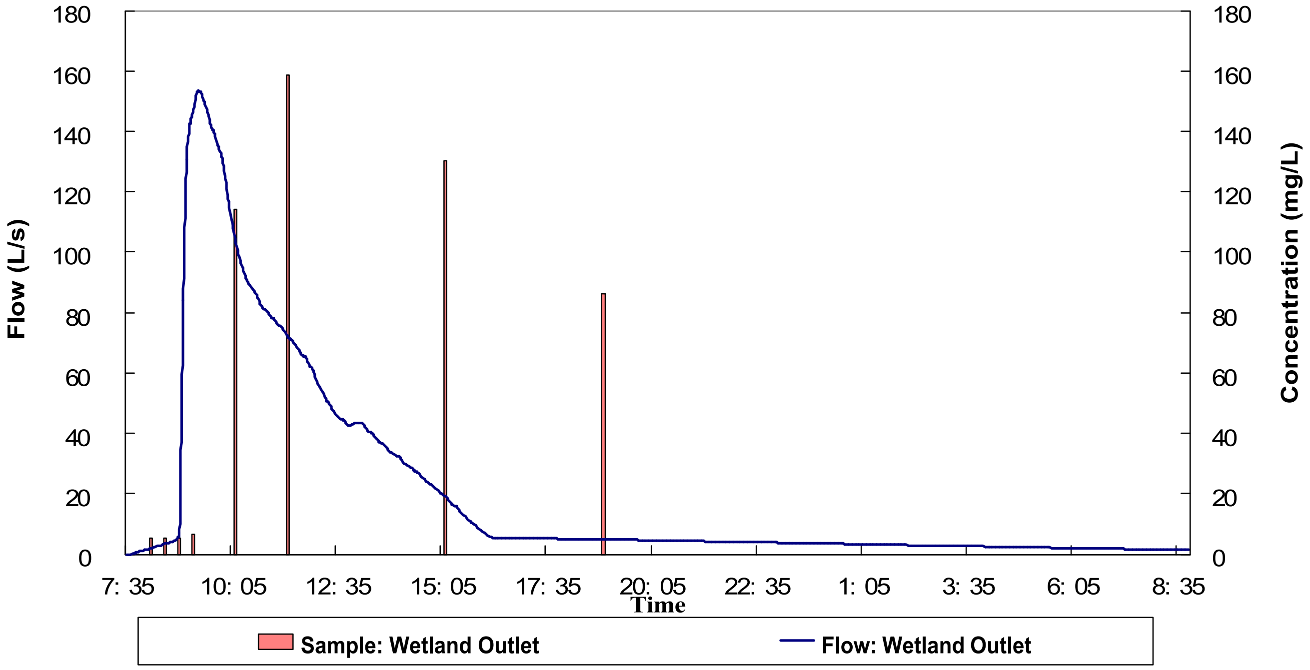
Maximum median TDS EMC of 109.5 mg/L was observed at the wetland outlet, whereas the minimum median TDS EMC of 7.5 mg/L was found in the untreated runoff. Filtration systems such as rain gardens and StormFilter are thought to be good at removing dissolved pollutants. The median effluent TDS EMC from media filters was 56 mg/L, which is the lowest compared to other BMPs as reported in the BMP database. Assuming the StormFilter onsite achieved similar level of TDS EMC, the 109.8 mg/L average effluent EMC of the StormFilter-wetland system shows that there might be significant amount of TDS released by the wetland.

Figure 7: Box Plots-TSS and TDS EMCs



*UR: Untreated Runoff; SO: Swale Outlet; SI: StormFilter Inlet; WO: Wetland Outlet

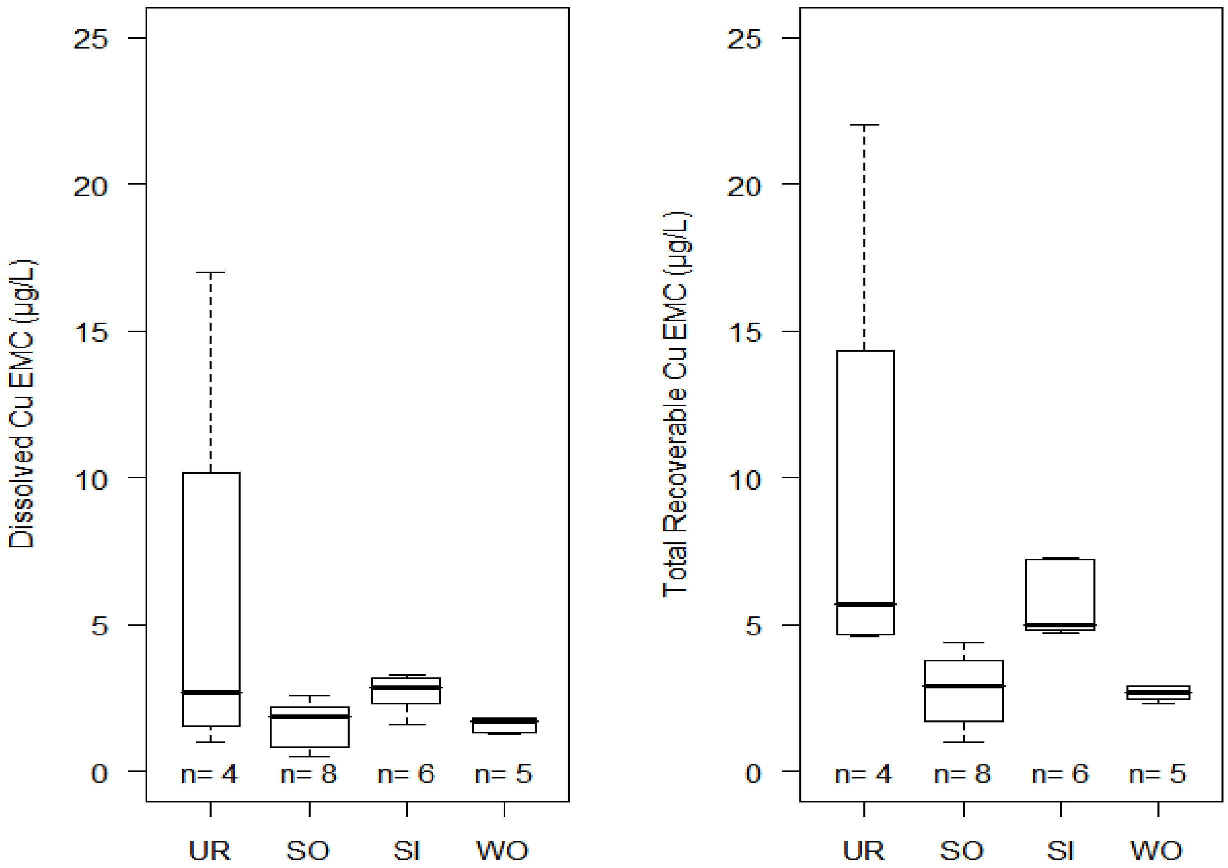
Figure 8: Discrete Analysis of TSS during 09/08/2008 Storm



3.2 COPPER

As can be seen in Figure 9, a large portion of copper presented in the stormwater runoff from site was in the dissolved form. 61.6%, 58%, 47%, and 59.9% of total copper existed in dissolved form for untreated runoff, swale outflow, StormFilter inflow and wetland outflow respectively. Untreated runoff dissolved and total recoverable copper concentrations were consistent with findings of Kennedy (2003). The median values for copper measured at StormFilter inlet were higher than that at the swale outlet and were nearly at the same level as the untreated runoff, as might be expected. As the swale outlet only measured the treated runoff from the lower parking area, roadway runoff from the western route and untreated busway runoff contributed to a large portion of the total copper concentration in the StormFilter inflow. The box plots do not show significant reduction of copper along the treatment train which is consistent with the finding that TDS was not well treated by the treatment train system. However, mean and median values for both total and dissolved copper EMCs from the swale outlet (mean: 2.8 and 1.6 µg/L; median: 2.9 and 1.85 µg/L for total and dissolved copper respectively) and wetland outlet (mean: 2.6 and 1.6 µg/L; median: 2.7 and 1.7 µg/L for total and dissolved copper respectively) were much lower than the median effluent EMCs reported in the international BMP data base by other studies (Biofilters: 10.7 µg/L for total copper and 8.4 µg/L for dissolved copper. Wetland basins: 4.2 µg/L for total copper and 7.4 µg/L for dissolved copper), which indicates the treatment train is effective at removing copper.

Figure 9: Box Plots-Dissolved Cu and Total Recoverable Cu

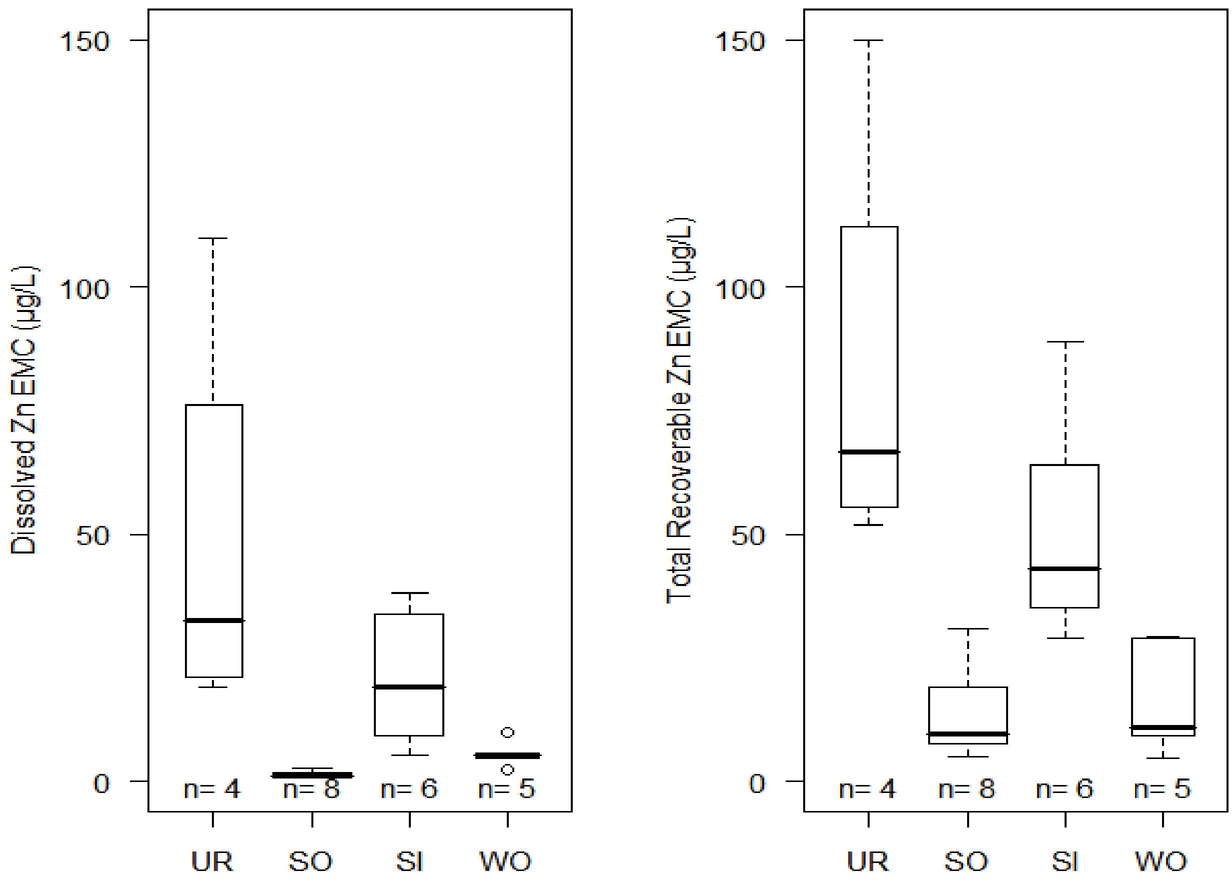


*UR: Untreated Runoff; SO: Swale Outlet; SI: StormFilter Inlet; WO: Wetland Outlet

3.3 ZINC

The median EMCs of total recoverable zinc measured at the untreated runoff, swale outlet, StormFilter inlet and the wetland outlet were 66.5, 9.45, 43, and 11 µg/L. There were 57.9%, 10.38%, 41.1%, and 33.7% of total zinc in dissolved form for untreated runoff, swale outflow, StormFilter inflow and wetland outflow respectively. Untreated runoff zinc concentrations were nearly half of the median values (283 and 170 µg/L for total zinc and dissolved zinc respectively) reported in other studies in the Auckland region, but the mean and median values were within the range reported in areas outside the Auckland area (Kennedy, 2003). Higher zinc concentrations were observed in minor storms that were less than the assumed first flush volume. The maximum untreated runoff zinc concentration was observed during the 1.5 mm storm on 18/11/2008, which did not produce any runoff from the wetland outlet. Similarly, maximum StormFilter inflow zinc concentration was observed during a 4.8 mm minor storm. In addition, the two minor storms both occurred “after hours” when most of the parking spaces were exposed, potentially allowing more pollutants to be picked up. Swale outlet and wetland outlet samples had consistently low dissolved zinc concentrations and were well below the effluent EMCs reported in the International Stormwater BMP database (25.4 and 17.9 µg/L for biofilters and wetland basins respectively). The box plots (Figure 10) show no overlap between the influent and effluent EMCs for the swales system and StormFilter-wetland system which indicate significant reduction of zinc for both systems, although the data sets are too small to satisfy the assumption of normal distribution.

Figure 10: Box Plots-Dissolved Zn and Total Recoverable Zn



*UR: Untreated Runoff; SO: Swale Outlet; SI: StormFilter Inlet; WO: Wetland Outlet

3.4 REMOVAL EFFICIENCY

Table 3 presents the preliminary pollutant removal efficiencies achieved by the treatment systems. Due to the challenges experienced in collecting concurrent samples at all sampling stations, only a few storms were available for mass removal efficiency (MRE) calculation. These values presented are just indicators and are insufficient to be used to assess the overall system performance. Furthermore, discussion of the inadequacy of a percent removal statistic in characterizing performance is beyond the scope of the current paper, but data is presented in the absence of an alternative, readily accepted metric.

For the two storms assessed, the swales system had a better percent reduction of zinc than the StormFilter-wetland system, whereas higher TSS removal was achieved by the StormFilter-wetland system. Negative TDS removal efficiency indicated that dissolved solids were released by the treatment system. Lower copper removal efficiency could be caused by the low inflow concentrations and does not mean that the system was not effective in removing copper. Comparison of the system outlet concentrations with effluent pollutant loads reported in the International Stormwater BMP Database actually shows that the swale-StormFilter-wetland treatment train system has a very good ability to reduce pollutant loads discharged to receiving water.

Table 3: Pollutant Removal Efficiencies

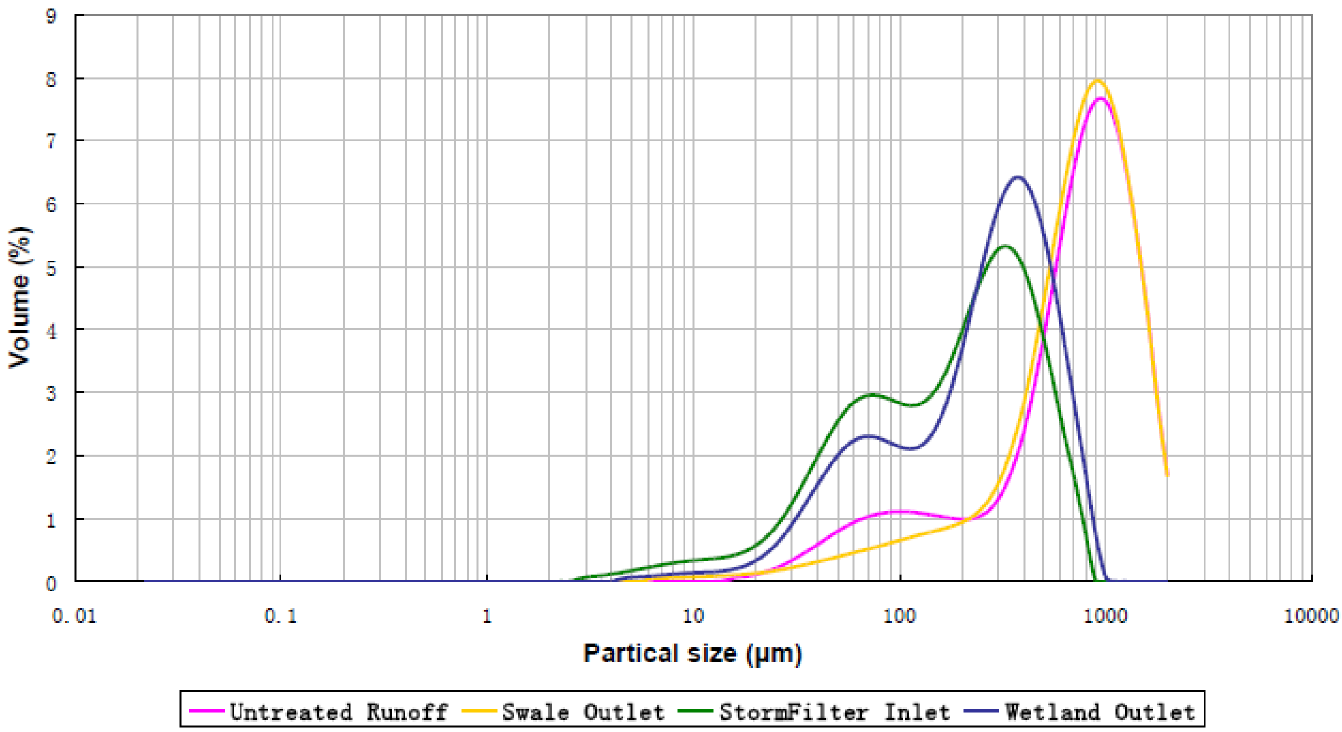
System	Storm Date	Rain (mm)	TSS	TDS	Heavy Metals			
					Dissolved Cu	**Total Cu**	**Dissolved Zn**	**Total Zn**
Grassed Swales	2008-11-23	18.2	52%	-900%	21%	45%	98%	90%
	2008-12-23	61.7	74%		13%	67%	95%	87%
StormFilter /Wetland	2008-12-9	36.5	67%	11%	31%	43%	39%	62%
	2009-1-18	6.9	80%	-38%				

3.5 OTHER OBSERVATIONS

The pH levels through out the treatment train did not show substantial variations. The minimum pH value of 5.99 with a standard deviation of 0.21 was observed in the untreated runoff during the 18.2 mm rainfall on 23/11/2008, where as the maximum pH value of 7.46 with a standard deviation of 0.11 was observed in the swale outflow during the 14.3 mm rainfall on 23/10/2008. Median values of pH levels found in untreated runoff, swale outflow, StormFilter inflow and wetland outflow for all the storms measured were 6.12, 7.24, 6.83 and 6.94 respectively, which shows a good buffering capability of the swale system.

PSD analysis was limited by instrument availability. Figure 11 below shows a typical PSD for the 18.2 mm storm on 23/11/2008. Laser diffraction particle analysis determines the particle size according to the volume percentage and does not account the particle density. Presence of one or two organic matter such as leaves that have large surface area and very low density could contribute to a large portion of the overall volume percentage. The laser diffraction analysis uses obscuration as a measure of how much sample is in the beam at any one time. Multiple scattering may occur and ruin the measurement if the obscuration is too high, whereas insufficient signal will be detected and adversely affect the precision if the obscuration is too low. The Malvern Mastersizer 2000 used for PSD testing generally requires an obscuration between 10% and 20%, whereas the average obscuration of all the samples tested was only around 3%. Due to the low TSS concentrations and inadequate sample volumes, the accuracy of the PSD results is questionable.

Figure 11: PSD Results for Storm on 23/11/2008



4 CONCLUSIONS AND RECOMMENDATIONS

- Continued monitoring of the treatment train is required to obtain sufficient water quality data to assess overall pollutant treatment capability in a statistically significant manner. Fortunately, continued monitoring is planned and will expand to include the rain gardens on the western route of the treatment train and the hydrologic monitoring at the final outlet to evaluate the overall performance of the treatment train as a whole. Initial indications suggest that overall the treatment train is very effective at controlling a suite of pollutants of concern in the Auckland region.

- The site is very clean compared to most urban runoff. Wetland outflow had consistent low TSS EMCs (mean: 20.7mg/L, median: 5.1 mg/L), except for storms that experienced discharge over the high-flow weir. Disturbance and resuspension of sediments during these events, and reduced overall detention time likely increased the effluent TSS EMC. TDS was not well treated by the system. There was an increasing trend of TDS EMCs throughout the treatment train.

- The system did not show significant percent reduction in copper due to the very low influent concentration. However, the average effluent concentration (median EMC: 2.7 and 1.7 μg/L for total and dissolved copper respectively) was much lower than the limit reported by other studies and indicates a good system performance.

- The grassed swale system was very effective at preventing zinc in the discharge. The median effluent total zinc EMCs for the swale system and the StormFilter-wetland system were 9.45 and 11.0 μg/L respectively.

- The swale system had good buffering capability for pH (mean: 6.24 for untreated runoff, 7.14 for swale outflow).

- Regular maintenance is required at the wetland outlet channel to avoid ponding and blockage by excess vegetation.
- To ensure proper function, series design and installation of stormwater treatment systems require detailed consideration of system hydraulics.
- Peak flow control for frequently occurring events is substantial. Results are encouraging for application to low impact development scenarios, as the design paradigm places emphasis on hydrologic control for the "everyday" type of event.

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