EVALUATION OF RAIN GARDENS IN AUCKLAND REGION

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ABSTRACT

The Auckland Regional Council (ARC) is in the process of reviewing its *Stormwater Management Devices: Design Guidelines Manual, Technical Publication 10, Second Edition (TP10 2003)*. Rain gardens are components of 'low impact design' stormwater management systems that have been used in the Auckland region for more than 10 years. Rain gardens (also known as bioretention basins and biofiltration basins) are one of the preferred management options used in the Auckland region to treat stormwater. The ARC conducted a field evaluation of 41 rain gardens from 30 sites in the Auckland region in 2006. The evaluation included analysis of the rain gardens media depth, particle size distribution, and the organic matter content. Permeability of the media was determined using a falling head *percometer*. Variation in the design and construction of the rain gardens was evaluated by visual inspections and documented by photographs. Two rain gardens were assessed in 2007 and 2008 by measuring inlet and outlet flows and evaluating water quality monitoring data.

KEY WORDS

storm water treatment, constructed rain gardens, best management practices, contaminated runoff

PRESENTER PROFILE

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1. INTRODUCTION

Rain gardens are a common stormwater treatment device used in the Auckland region. Rain gardens are effective stormwater treatment systems and can be an important component of an urban landscape design. Rain gardens reduce contaminants by variety of chemical, physical and biological processes. These retained stormwater runoff in the depression area and in the soil substrate media, and slowly filters through the media. The vegetation is an important in maintaining the media porosity and providing other ancillary benefits like habitat and beautifying the environment.

When rain gardens are designed according to TP10, it considered as meeting treatment objectives of the stormwater consent requirements. Currently, there is no specific protocol to evaluate the treatment performance of rain gardens after installation. The ARC inspection guideline (http://www.arc.govt.nz/environment/water/stormwater/compliance-checksheets.cfm) provides general procedures to evaluate the need for maintenance frequency of the rain garden, with the assumption that if the rain garden is properly maintained treatment performance is assured.

The ARC evaluated the construction quality, media composition of 41 rain gardens, and treatment performance of some selected rain gardens. Construction quality was assessed by evaluating the degree of erosion at the entrance and exit of the rain garden, evidence of flooding or bypassing, plant density, and storage volume. Media composition was assessed by determining its particle size distribution, organic matter content and percolation rates. Treatment effectiveness was assessed by monitoring the inflow and outflow runoff rates and the concentration of contaminants for few selected rain gardens. The evaluation is explained further below.

2. SELECTED SITES AND METHODOLOGY

Selected Sites

Forty one rain gardens from 30 sites in Manukau City, Auckland City, Waitakere City, Northshore City, and Rodney District were selected for evaluation to provide a representative sample of the rain gardens in the Auckland region (Figure 1).

Sites included:

- three rain gardens in Manukau City
- nine rain gardens in Auckland City
- seven rain gardens in Waitakere City
- seven rain gardens in Northshore City
- four rain gardens in Rodney District

Methodology

In 2006, 41 rain gardens were visually assessed and documented by photographs. The rain gardens' media depth, permeability, particle size analysis, organic matter content, and plant density were also determined.

Visual Assessment, Media Depth and Plant Density

The rain gardens structures were measured and documented by photographs. The media depths were determined using an auger. Plant density was evaluated counting number of plants for rain garden area, and then determined the average.

Percolation Test

Percolation was measured using single ring Percometer (Figure 2 & 3) developed by the University Minnesota (http://www.extension.umn.edu). The Percometer comprises a 150 mm diameter plastic tube with a float and measuring assembly within the tube. The instrument is placed in a hole and filled with water. As the water elevation falls within the tube the drop in water is measured.

Figure 1: Rain garden site survey locations

The percolation test was performed by placing the instrument into a 300 mm deep and 200 mm diameter hole. The media was soaked for about 30 to 60 minutes to ensure the media was saturated.

After soaking, the water level was adjusted to 300 mm from the borehole invert. The time taken for the water to fall (in time intervals of 5 minutes) was measured and recorded. Water was then added to bring the level up to 300 mm mark and the test was continued until two successive water level drops did not vary by more than 3 mm. The percolation rates were calculated as specified in University of Minnesota fact sheet (www.extension.umn.edu) and the Alberta Government Municipal Handbook (www. municipalaffairs.alberta.ca).

The calculated percolation rates were converted to permeability values using the Green-Ampt equation (Ahmed and Gulliver, 2009).

Organic Matter Content and Particle Size

Media samples were collected using 200mm sand auger. Samples of the media were taken at three depths: 0-50 mm, 50 – 100 mm, and 100 – 150 mm and analyzed for both organic matter content and particle size. The testing of the core samples for organic matter content and particle size was undertaken by National Institute of Water and Atmospheric Research. Organic matter content (as a percentage) was measured through loss on ignition tests. The results are determined by weighing a known quantity of dried sample before and after ignition at 450ºC. Particle sizes were determined by sieve analysis.

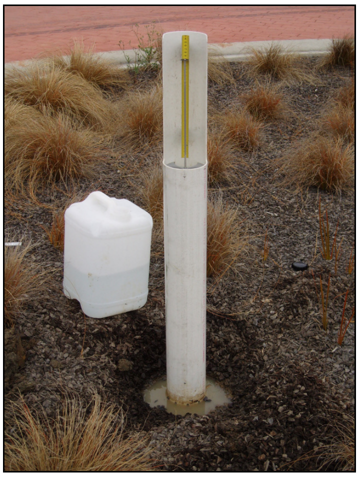


Figure 2: Percometer at beginning of test

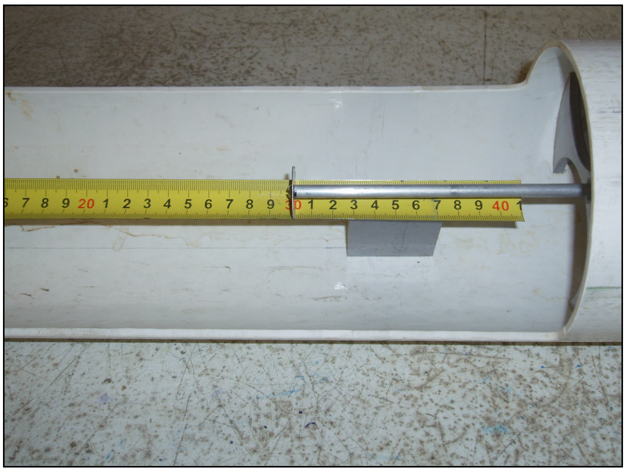


Figure 3: Measuring system on Percometer

3. FINDINGS

3.1 DESIGN VARIATIONS

There was considerable variation in the design of the 41 rain gardens studied. Typical variations observed were:

- Erosion protection structures around inlet or outlet
- Overflow structure elevation

- Planting densities
- Mulch layer composition and depth
- Media composition and depth

Erosion Protection

About 20% of the rain gardens evaluated showed evidence of erosion at the inlet (Figure 4). Typical causes of erosion were due to concentrated flow by piped inflow (Figure 4) and lack of erosion protection at curb cuts (Figure 6).

The type of inlet erosion protection structures observed in rain gardens ranged from level spreaders, Reno mattresses, and concrete with embedded riprap (Figure 5).

Level spreaders generally provided good erosion protection. In some rain gardens, the level spreaders did not have end caps which resulted in erosion at the ends of the spreader pipes.

The rain gardens constructed on flat sites showed the least amount of erosion, as expected. These rain gardens provided diffuse overland flow into all areas of the rain garden. Most of the outlet structures observed consisted of standard catch pits with under-drains. These structures produced no obvious erosion. In some rain gardens erosion was observed at the outlet of under-drain pipes and banks due to over flow (Figure 7 & 8).

Figure 4: Inlet erosion at St Lukes, Karaka Cove, Kia Ora and Oranga Community centre rain gardens

Figure 5: Inlet channelization protection (Rangitoto College site, Northshore)

Figure 6: Curb cuts and scouring (Wesley Community Centre, Mt Roskill)

Figure 7: Outlet erosion at Kia Ora Road rain garden, Birkenhead

Figure 8: Overflow bank erosion at Kia Ora Road rain garden, Birkenhead

Overflow Structure Elevation

The design of the overflow structure is an important component of the rain garden, as it regulates the amount of water stored in the rain garden for treatment. The volume of water required to be treated in the rain garden is the water quality volume (WQV). The portion of runoff stored above the media is the live storage volume and is usually 40% of the WQV. The overflow structures are designed to discharge volumes of stormwater greater than the designed WQV.

TP10 specifies a maximum of 220 mm storage depth for the live storage volume. A large portion (56%) of rain gardens evaluated possess overflow structures less than the recommended height, possibly resulting in reduced treatment as a portion of the WQV would be bypassed rather than retained. A summary of the overflow elevations measured are listed in Table 1.

Table 1: Overflow Structure Levels variation

Overflow structure Level from top soil level (mm)	No of rain gardens	Comment
0	11	27% of rain gardens measured did not provide live storage
0 -100	12	29% of rain gardens measured had less than 150 mm pool depth
150 - 220	10	24% of rain gardens measured provided suggested pool depth as in TP 10
> 220	8	20% of rain gardens measured provided greater than recommended pool depth as in TP10

Plant Densities

Plant densities were generally well established in the rain gardens assessed. Generally plant density increased with the age of the rain garden. About 83% of sites were determined to have sufficient plants and coverage. Plant spacing varied from 0 - 5 plants per square meter over the rain garden's surface.

Of the 41 rain gardens assessed three had no plants. In four rain gardens the planting was determined to be insufficient, due to plant die-off. Poor plant selection, dry conditions, and spraying from residents (personal communication with North Shore City Council) appeared to be the main cause of reduced plant densities in the rain gardens evaluated.

Ground Cover or Mulch Layer

The depths of mulch varied from no mulch to 250mm in the rain gardens evaluated. About one third of the rain gardens had a mulch depth over 80 mm and one third had no mulch. The rain gardens with no or minimal coverage showed evidence of erosion of the substrate media, possibly resulting in increased media clogging as a result of accumulation of fine sediments (Figure 9).

Rain gardens with mulch depths above 75 mm appeared to have an issue with the mulch floating away (Figure 10).

Figure 9: Good health Site

Figure 10: Kirkbride Road Site

Media Depth

The rain gardens media depth affects the treatment and is an important consideration in the design of a rain garden.

T P10 recommends a minimum media depth of one metre not including the 400mm drainage layer. The one metre of media is assumed adequate to provide stormwater treatment.

The media depth measured in the 41 rain gardens assessed was variable and is summarised in Figure 11. The depth of the media of about 32% of the rain gardens were not measured due to the presence of rocks (non-uniform stones sized 30-50 mm in diameter) in the media. Of the 41 rain gardens assessed, about 25% had the TP10 prescribed media depth.

3.2 PERMEABILITY OF THE MEDIA

Permeability of the media was indirectly measured using the method specified in the section 2. Due to the shallow depth of the media in some rain gardens it was difficult to measure the in-situ percolation rate for some of the rain gardens.

The measured permeability ranged from 3 mm hr-1 (Te Puru Park site, media has a very high clay content) to 7500 mm hr-1 (Rangitoto College Site, media consists with 100% sand).

Of the 41 rain gardens evaluated (Figure 12):

- 2% had conductivity between 500 – 1000 mm hr^{-1}.
- 17% could not be measured due the shallow media depth (less than 300 mm)
- 22% had extreme permeability rates (either greater than 1000 mm hr^{-1} or less than 5 mm hr^{-1})
- 59% had permeability conductivity between 10 – 500 mm hr^{-1}

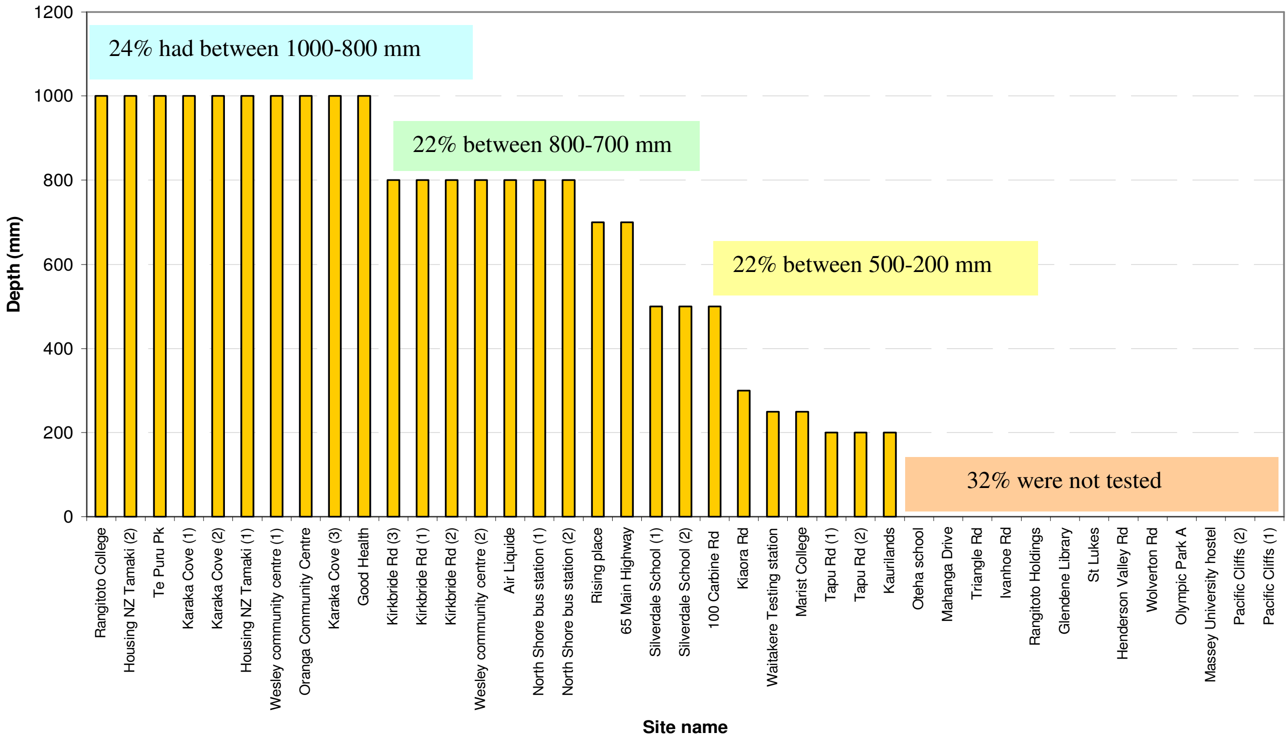


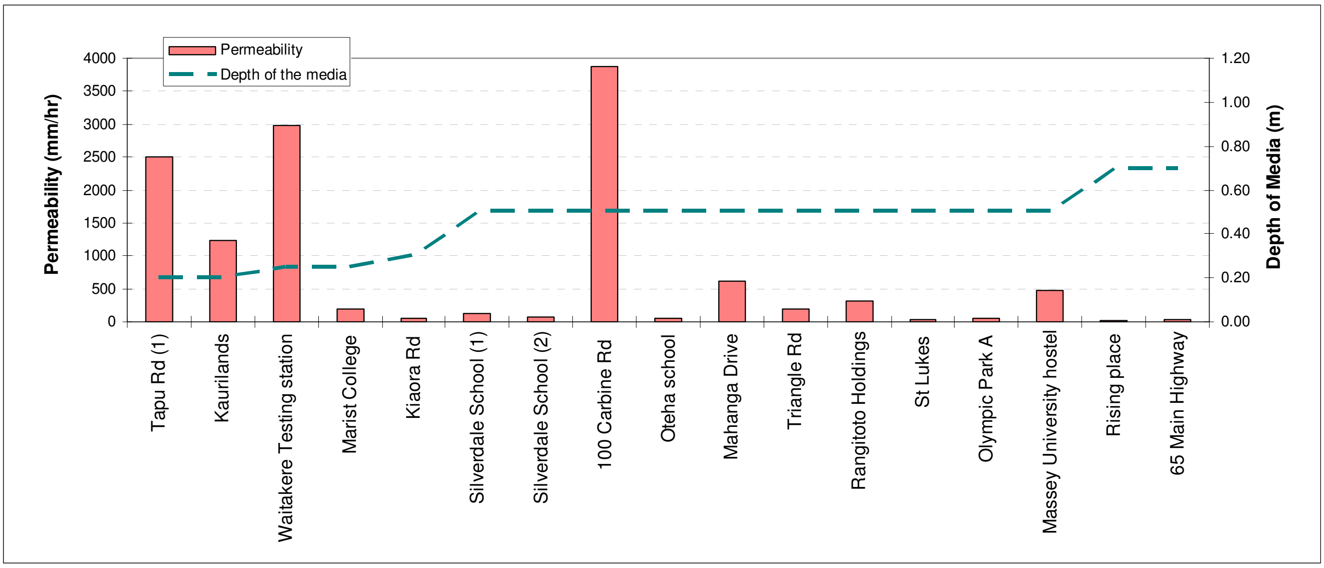
Figure 11: Media depth variation for surveyed rain gardens

The highest permeability rates measured were observed at the following sites: Rangitoto College, 100 Carbine Road, Waitakere Vehicle Testing Site, Oranga Community Centre Site and Kauri Lands Site.

The Rangitoto College rain garden media can be characterized as a sand filter as there were no plants within the live storage area and the media was very sandy. The other sites with high hydraulic conductivities had a media consisting of a large portion of silica sand and pumice mix. The media from these sites had less than 2% fines (particle size less than 63 μm). The high percentage of coarse particles in the media is likely to have been the reason for the high permeability measured.

The majority of the rain gardens had permeability ranging from 10 – 500 mm hr^{-1}. The average permeability measured was 480 mm hr^{-1} (excluding the Rangitoto College site).

The lowest permeability measured was less than 5 mm hr^{-1}, at the Krikbride Road site 3, Te Puru Park and Karaka Cove sites. The media at these sites were reported having 25% of particles finer than 63 μm.



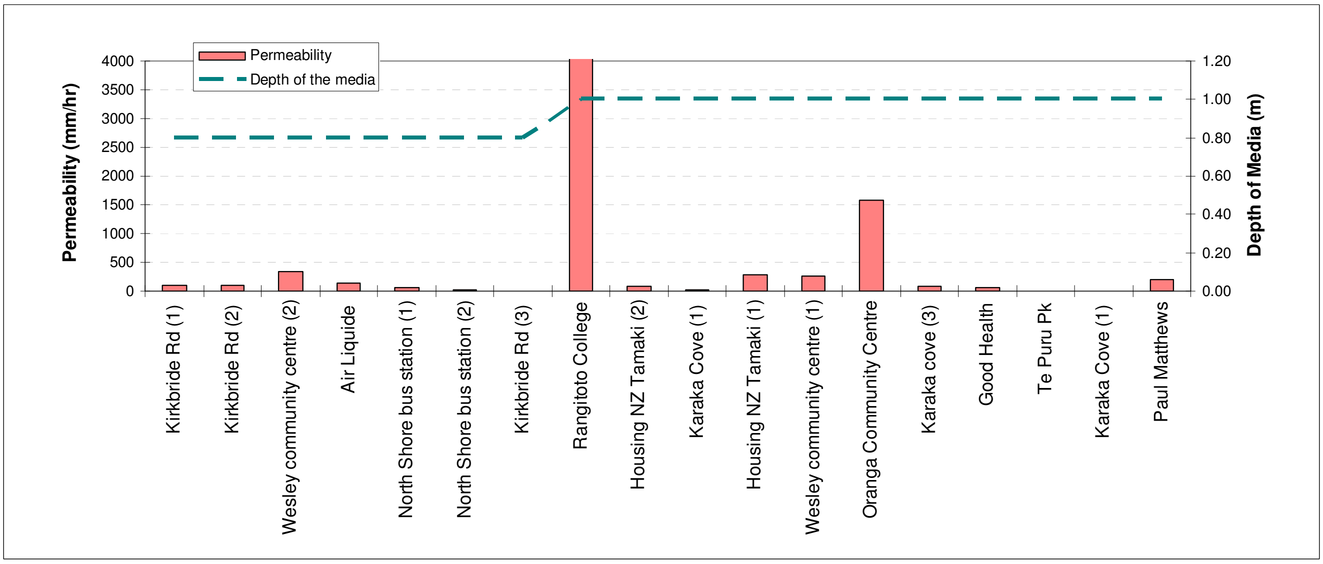
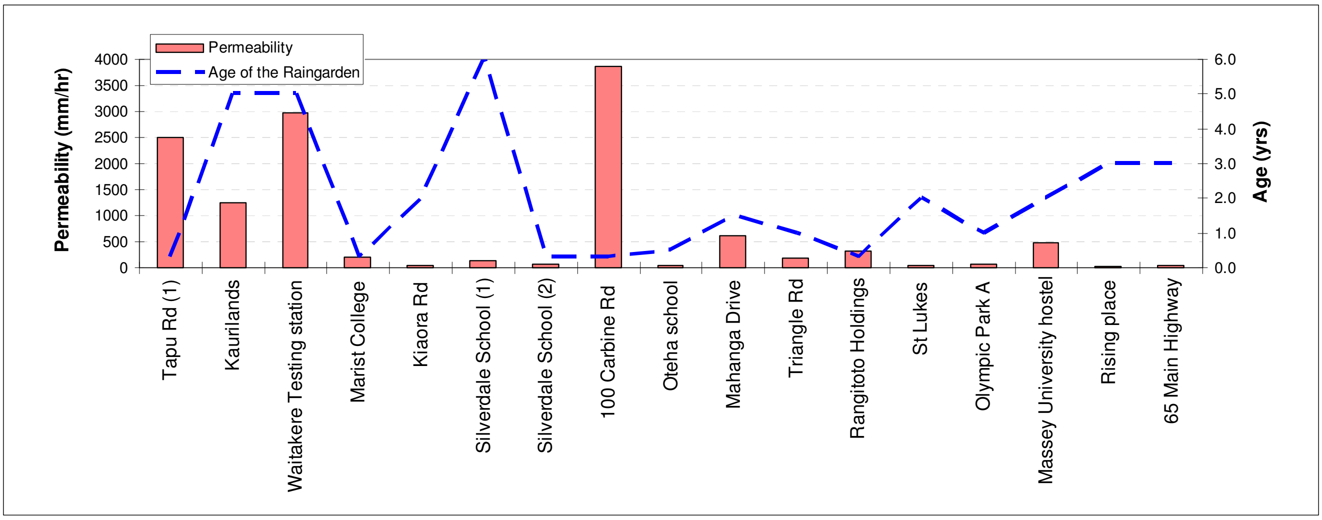


Figure 12: Distribution of permeability (mm/hr) with media depth (m)



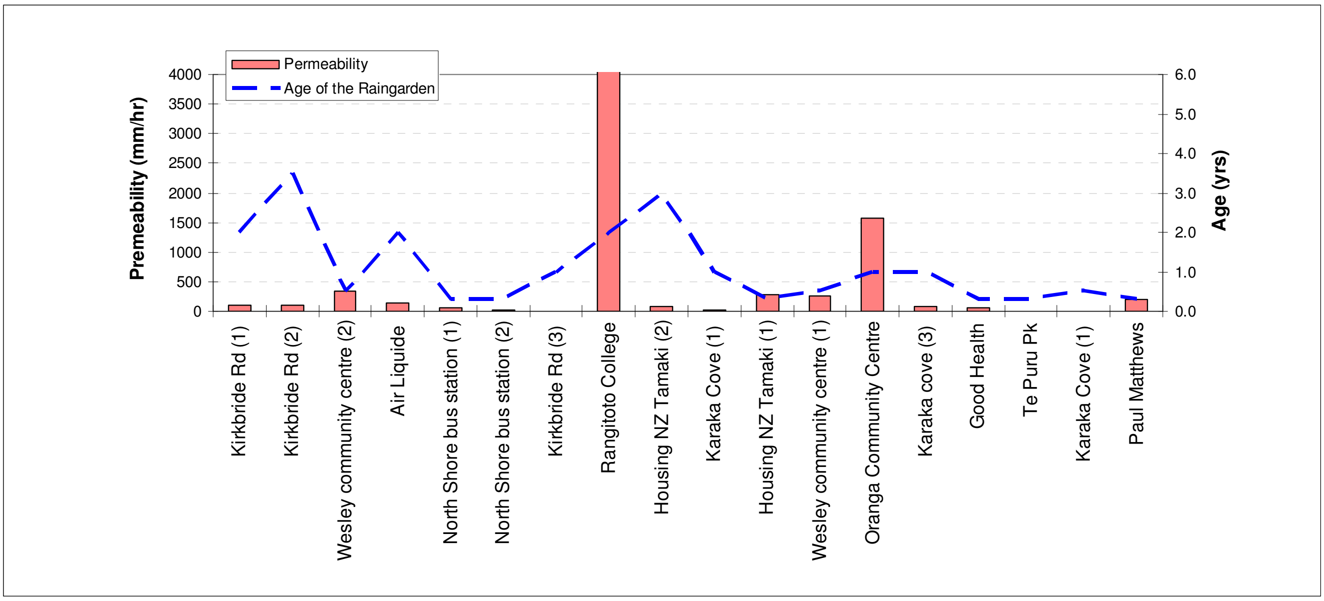


Figure 13: Distribution of permeability (mm hr^{-1}) with Age of the rain garden (yrs)

Permeability was expected to reduce over time due to clogging and settling of the media and then increase as the plant roots develop. However, no correlation with permeability was found between the media depth (Figure 12) and age of the rain garden (Figure 13). The rain gardens with high plant density have lower permeability values.

3.3 CORE SAMPLE ANALYSIS

Particle size

Core samples were obtained at three depths within the media profile to determine particle size. All media samples analysed had less than 25% of fines (particle size < 63 µm), the sample median value was 10% of fines (particle size < 63 µm) (Figure 14). Analysis results of the core samples indicates 62% of the rain gardens tested had well mixed media based on the distribution of particle size through the media profile.

Results indicated the following:

- 62% of sites had consistent particle distribution throughout their cores.
- 26% of sites indicated varying layers of fine particles mixed in the media.
- 12% of sites showed an increase in fine particles in the surface layers of the rain garden, which may be indicative of trapping of incoming fine sediments from runoff.

There was no relationship between fine particles (< 63 µm) and the permeability (Figure 15). However, the highest permeability measured was associated with the percentage of coarser particles and some of the slower permeability rates were observed had media with more than 25% fines.

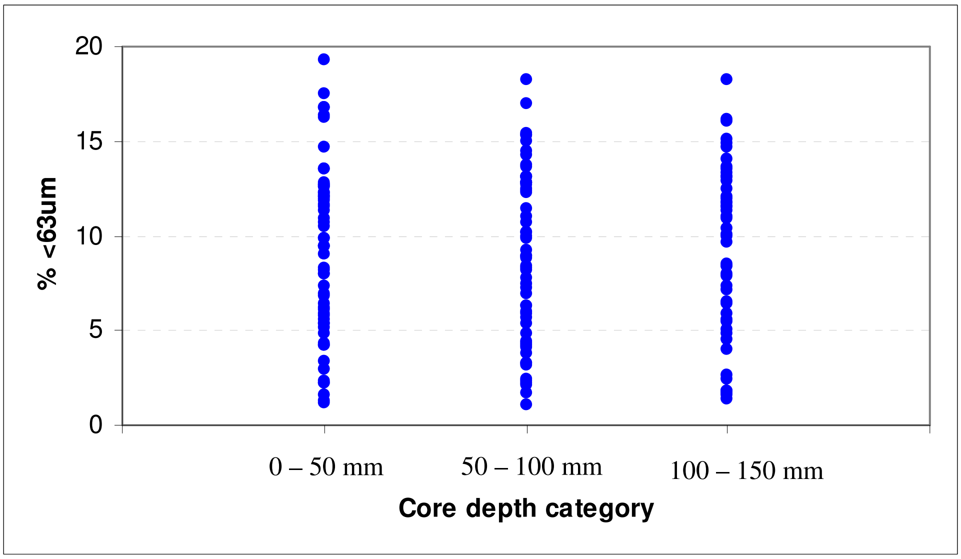
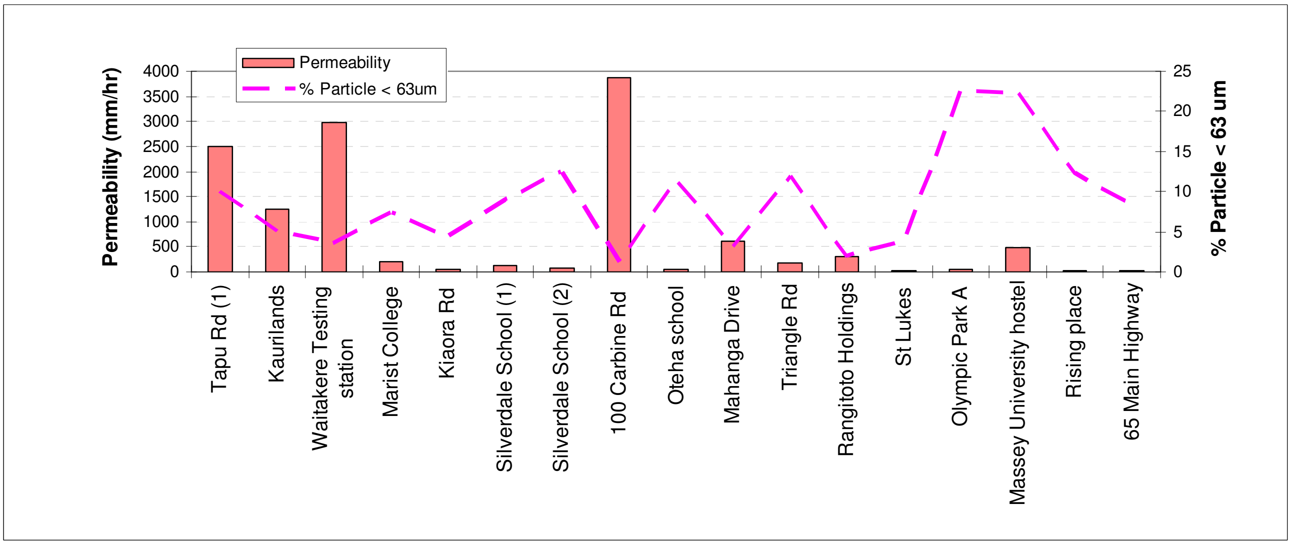


Figure 14: Distribution of particles less than 63 µm with different depth categories



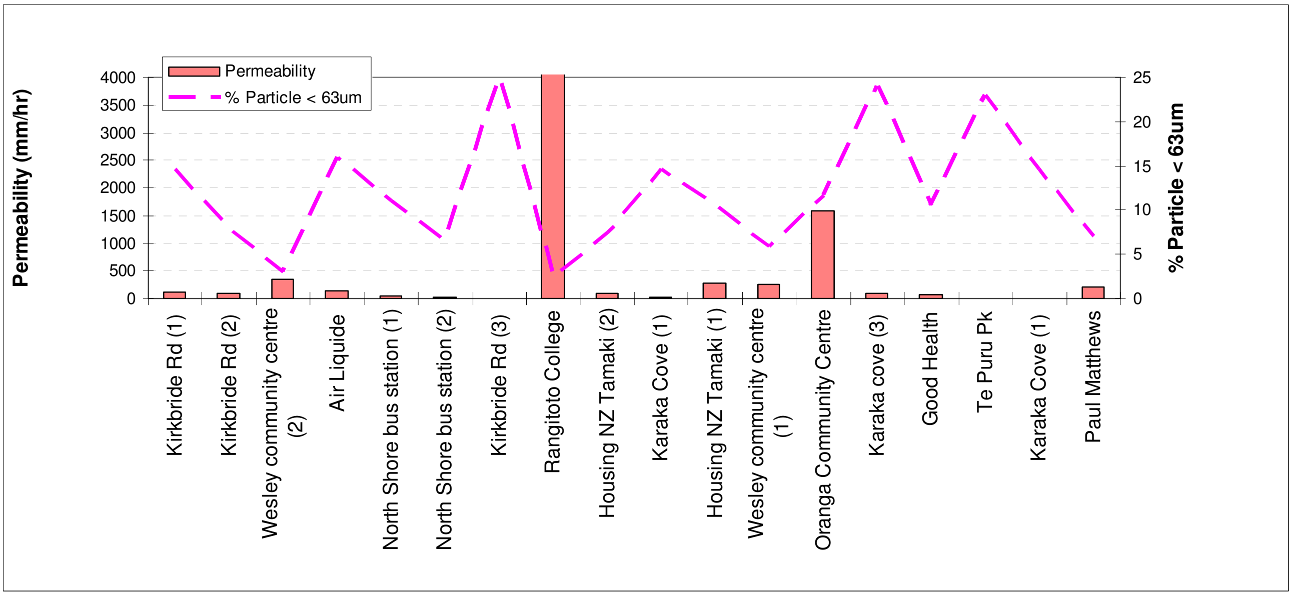


Figure 15: Distribution of permeability (mm hr^{-1}) with % particles finer than 63 µm.

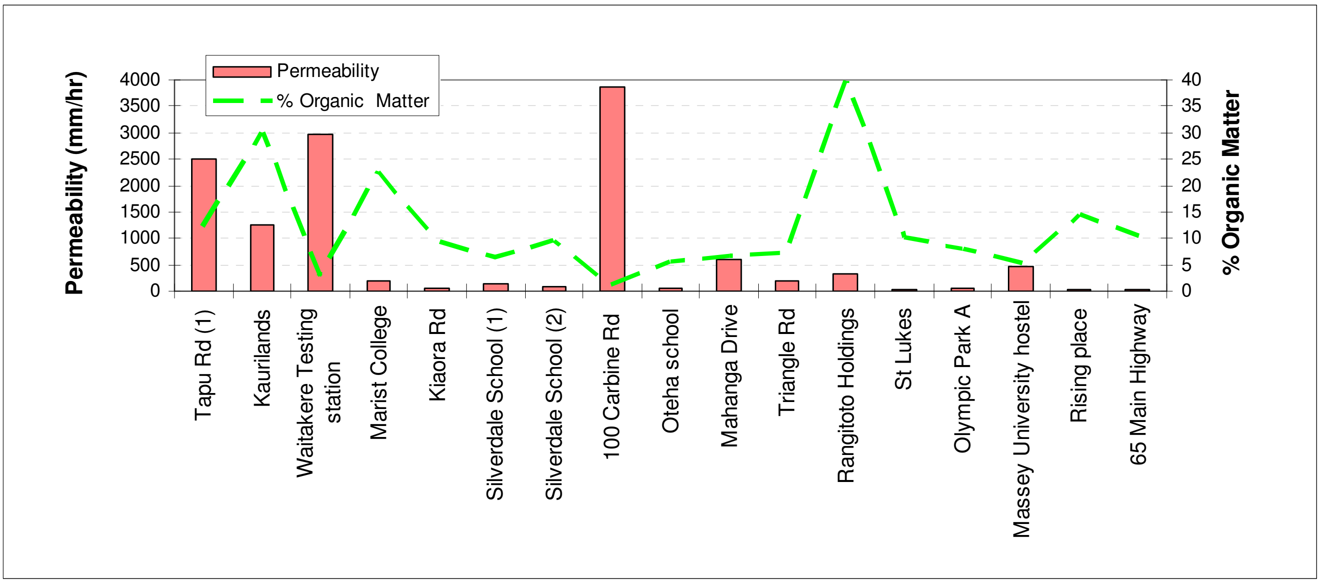
Organic Matter Content

Organic matter content of the rain garden media ranged from 2% to 45% (Figure 16). There was no statistical relationship between organic matter and permeability.

The Rangitoto Holdings rain garden had the highest percentage of organic matter measured (40%). The Carbine Road rain garden had the smallest percentage (1%) of particles finer than 63 μm and the lowest organic matter content (1%) and a permeability of 4000 mm/hr.

Very little organic matter was present in the media of the Waitakere Vehicle Testing Station (WVTS) site in Waitakere City. The average organic matter measured for Waitakere Vehicle Testing Station was 3%. Over all the sites tested, the average organic matter content was about 11%.

Healthy plant densities and growth were associated with high organic matter content media. However, no relationship between organic matter content of the media and plant density could be found.



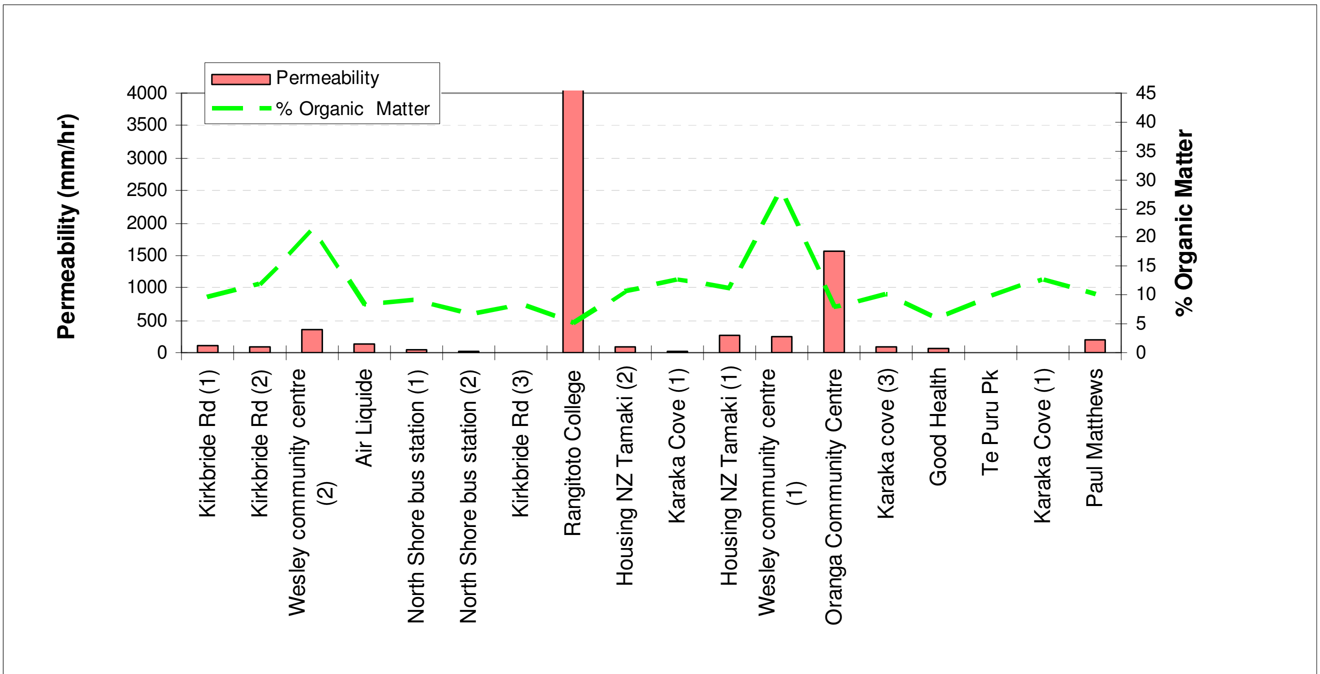


Figure 16: Distribution of permeability (mm/hr) with % organic matter

4. PERFORMANCE ASSESSMENT OF SELECTED RAIN GARDENS

The rain garden survey revealed that there was considerable variation in the construction of the rain gardens surveyed, when compared to TP10 specifications. Two rain gardens were selected and monitored in detail to assess their performances. The rain gardens assessed were located at the Waitakere Vehicle Testing Station site (WCVTS) and the Paul Matthew Road site.

4.1 WAITAKERE VEHICLE TESTING RAIN GARDEN

General

The WCVTS rain garden is one of the oldest rain gardens in the Auckland region (about 10 years old), and was designed to treat the facility's parking area runoff. The rain garden is densely vegetated with flax plants and has a media depth of 300 mm. The permeability measured in the rain garden's media was about 3000 mm/hr. The overflow structure height was determined to providing sufficient storage volume. .

Monitoring

The rain garden's treatment performance of total suspended solids, total zinc and total copper was determined monitoring a number of parameters. Inflow and outflow were measured using weirs. Water samples were collected on a time basis using an ISCO sampler for 60 seconds interval with a stage accuracy of ±1 mm. Rainfall was measured with a tipping-bucket gauge and logger. The recording interval was 60 seconds and the resolution was 0.2mm of rain (ARC 2007).

Water quality data were obtained at five minutes intervals for eight independent rainfall events. Total Suspended Solids, particulate zinc, particulate copper, dissolved zinc and dissolved copper were measured in 94 inlet samples and 82 outlet samples (ARC 2007).

Contaminant loads were estimated using measured flow hydrograph using STORMQUAL model (Timperley et al, 2005) and then the contaminant loads were estimated over the entire period of flow monitoring for total suspended solids, total zinc, dissolved zinc and total copper. Model parameters were calibrated before any application.

Results

Rainfall, inflow peak, volume and the rain garden discharge are shown in Table 2. The loads and yields calculated from STORMQUAL are given in Table 3.

Table 2: Rainfall, runoff for monitored events

	Peak Inflow ($l\ s^{-1}$)	**Total flow volume**		
Event		**Inflow (m^3)**	**Bypass (m^3)**	**% Pass through media**
A	14	141600	22380	84%
B	1.8	23100	0	100%
C	7.2	112200	6960	94%
D	50.9	116400	62100	47%

Event D was very intense, and resulted in bypass of stormwater runoff. For other events the rain garden was determined to be above 85% hydraulically efficient. Overall hydraulic efficiency of the rain garden is about 76% for the monitored period.

Table 3: Inlets and Outlets Loads and Yields

Contaminant	**Inlet load (kg/247days)**	**Inlet yield (kg ha^{-1} a^{-1})**	**Outlet load (kg/247 days)**	**Outlet yield (kg ha^{-1} a^{-1})**	**Reduction (%)**
Total suspended solids	32.10	153.69	5.38	25.75	83
Total zinc	0.0902	0.4321	0.0178	0.0853	80
Dissolved zinc	0.0485	0.2321	0.013	0.0622	73
Total copper	0.0102	0.0487	0.0050	0.0241	51

Impacts of surface permeability rate

The percolation rate varies depending upon the sediment build-up rate at the surface layer, plant growth and root developments. The permeability rate of the rain garden media was measured in three locations in 2010. The permeability rate was determined to be in the range of 100 – 150 mm hr^{-1}., The underlying plant media is mainly pumice. The permeability rate of that media was determined to be 2500 mm hr-1. The surface of the media had an accumulation of sediment and was slightly darker in colour than the subsurface media, indicating an accumulation of organic matter and other debris in the top 50mm of media. The low permeability rate measured was likely due to sediment and organic materials build-up at the surface layer

A simple spreadsheet water balance model has developed using inflow and outflow hydrographs collected in Nov 2006 to June 2007 considering rain garden media properties and design details to evaluate impact of the permeability changes.

The simulated results showed that the permeability rate varied in the range of 125 mm hr^{-1} to 80 mm hr^{-1} for the monitored period of Nov 2006 to June 2007. Estimated results are within the same magnitude with the field-measured values (ARC 2010). The permeability changes can result due to clogging mechanism and plant growth.

The calibrated model was used to estimate the outflow hydrograph for different permeability rates. The estimated hydrographs were simulated through the STORMQUAL model and loads determined. Predicted load reduction efficiencies for different permeability rates are presented in Table 4.

Table 4: Predicted % load reduction for different permeability rates

	Estimated % Load reduction			
Contaminant	**150 mm hr^{-1}**	**100 mm hr^{-1}**	**80 mm hr^{-1}**	**40 mm hr^{-1}**
Total suspended solids	89	77	75	68
Total zinc	81	64	59	41
Total copper	65	66	60	41

4.2. PAUL MATTHEW RAIN GARDEN

General

This rain garden was installed in the winter of 2006 and received its first inflows in July 2006 as wash-off from a heavily trafficked local road with a single carriageway in each direction in a light industrial catchment (ARC 2008). The rain garden is planted with a single plant species, at a density of three plants per square meter to ensure rapid rain garden cover. The overflow structure height meets the design specification providing sufficient live storage. The initial permeability was measured and determined to be 220 mm hr^{-1} . Depth of the media is about 300 - 400 mm top soil and 600 – 700 mm subsoil. The rain garden construction was determined to meets design specification of TP10.

Monitoring

Inflow and outflow was measured by pressure transducers. Water samples were collected for 24 hrs and measured total suspended sediments, total phosphorous and nitrogen, ammonium, nitrate, total petroleum hydrocarbons, dissolved and total copper, lead and zinc, using standard methods (ARC 2008). A total of five events were monitored that had six or more discrete water quality samples collected at both the inflow and outflow.

Results

Rainfall, inflow peak, volume and rain garden discharge are shown in Table 5.

Table 5: Rainfall, runoff for monitored events

Event	Total Rainfall (mm)	Peak Inflow ($l\ s^{-1}$)	Total flow volume		
			Inflow (m^3)	Bypass(m^3)	% Pass through media
A	28.9	18	178	82	54
B	8.5	10	55	5	91
C	28.9	53	261	57	78
D	8.0	7	44	0	100
E	20.2	39	123	35	72

The data show that between 54% and 100% of inflow drained through the rain garden media. As expected, the two smallest percentages corresponded to the two largest events when much of the inflow bypassed the rain garden. There was a small volume of rain in events B and D, resulting in small bypass of the flow. Event B was the shortest in duration and was relatively small volume resulting in 10% of the inflow becoming bypass flow. Event D was the only event not to experience bypass of flow, reflecting the slightly longer duration rainfall.

Table 6: Rainfall, runoff for monitored events

Contaminant	Inflow ($\mu g\ l^{-1}$)	Outflow ($\mu g\ l^{-1}$)	Reduction (%)
Total suspended solids	56	2	96
Total zinc	746	21	97
Dissolved zinc	374	16	96
Total copper	20	20	No reduction
Dissolved copper	3	15	Leaching

NOTE: median values are presented in the Table

The concentrations of water quality determine that total suspended solids and zinc were significantly reduced. However, copper concentrations were different. The dissolved copper may have come from slow-release fungicides in the potting mix or chemical residual used on plants in the nursery.

Total suspended solids load in the outflow was just 1 to 3% of the inflow so the rain garden can be said to perform very well at removing the total suspended solids load for flow through the rain garden.

Impacts of surface permeability rate

The permeability of the media was about 220 mm hr^{-1} during construction. Topsoil permeability rates after one year were generally high, with a mean of 120 mm hr^{-1}. The rates were expected to reduce by up to 30% after the placement of topsoil and settling over the first six months of operation. The average reduction is about 45% after one year of construction. It appears that the rain garden has a very high sediment inflow and the rate of permeability reduction is very high..

5. CONCLUSION

Several observations can be made:

- The rain gardens in the Auckland region are different in design from one another.
- The media used in the rain garden had a range of permeability, depth, organic matter content, plant density and particle size. Permeability varied from 3 to 7600 mm hr^{-1}. The media depths measured revealed that 44% had less than the TP10 specified media depth. No correlation could be found between permeability and the depth, age, organic matter and percentage of fines of all the rain gardens. However there was a relationship between permeability with coarse textured media and plant density.
- Some rain gardens did not comply with the TP10 design guideline. For example the height of the outfall structure. This design produces a situation where WQV or live storage exceeded and bypass occurs.
- Erosion protection at the inlet and the outlet was good with 80% having adequate protection. Plant density was appropriate but problems identified with planting in the summer season causing plant death.
- Ground cover depths varied up to 250mm that caused problems with excess mulch (more than 75mm) resulted blockage of drains causing flooding.
- The Waitakere Vehicle Testing Station rain garden performs well with high removal efficiency, even though the subsoil media has very high permeability rate. The permeability rate of the surface of the media is the limiting factor that needs to be investigated further. Overall hydraulic efficiency was determined to be about 76% for the monitored period.
- Paul Matthew Road rain garden s received high Total Suspended Solids and zinc loadings. Contaminant removal rates are very high. Permeability reduction of the surface media was greater than expected.

6. FUTURE WORK

Several items identified to better understand rain garden performance:

- Monitoring of media compaction (bulk density) to understand the variation of permeability of the media.
- Measuring surface permeability rates annually on a selection of rain gardens to evaluate impact of particle clogging, plant growth and compaction.
- Monitoring of contaminant profile for selected rain gardens to determine effectiveness of the design over time.
- Evaluation of the current TP10 design methodology based on the information gathered.

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