BIO-FILTRATION RAINGARDEN, FROM DESIGN TO BUILT

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ABSTRACT

Biofiltration Raingardens are "gardens with purpose". They improve stormwater quality through filtration media and are considered a sustainable stormwater management device that can replace hard-engineered stormwater infrastructure while also meeting regulatory obligations.

Meeting the regulatory obligations is often the first consideration when implementing stormwater management solutions and undertaking best practicable options analysis. However, a change in focus to address specific contaminants of interest requires a different approach to achieve compliance with ICMP objectives and other obligations. Raingardens can provide the flexibility that is required and become the device of choice with respect to changes in focus of contaminant removal.

Raingardens have often been used as a centralized or decentralized stormwater management device and an important tool for water sensitive design. Raingardens can provide stormwater quality treatment, runoff attenuation, groundwater recharge and intangible value such as potential benefit human health and welling being whilst providing greater connection between the urban and natural environment.

This paper discuss various design methodologies, applications and potential challenges throughout the raingarden design phase and highlights some of the additional challenges that arise during construction by presenting examples from several projects in the Waikato and Auckland Regions. The presented case studies will expose the challenges faced during the construction phase and how these can be overcome during design evolution. .

Challenges include:

- Design to target specific pollutants
- High water tables
- Media selection
- Outlet Design
- Construction methodology
- Maintenance requirements

KEYWORDS

Stormwater, Raingarden, Water Sensitive Design, construction, compliance

PRESENTER PROFILE

Tony Wang has worked in a variety of capacities within and outside Stormwater Solutions over the past 7 years. He is responsible for environmental assessments, stormwater management, over land flow path design, hydrological and hydraulic modelling, compliance monitoring and successfully delivering both green and brown field projects within the private and public sector.

1 INTRODUCTION

Not only do raingardens have aesthetic benefits not provided by alternative stormwater management devices but it is also considered that they provide greater water quality benefits for a wider range of contaminants as a result of additional biological processes provided by plants. Therefore, raingardens are important for residential implementation.

From design to built, various challenges have been encountered in both the Waikato and Auckland Region. These challenges are discussed further in the following paper.

2 BACKGROUND: NATIONAL & REGIONAL GUIDANCE

The Resource Management Act 1991 (RMA) is New Zealand's primary legislation that sets out the requirements and national direction on how New Zealand's environment and resources are to be managed. The RMA requires regional and district resource management plans to be implemented by regional authorities to achieve the best practicable outcomes.

2.1 NATIONAL POLICY STATEMENTS

The National Policy Statement for Freshwater Management 2014 (Freshwater NPS) sets out the objectives and policies for freshwater management under the RMA. The Freshwater NPS and the New Zealand Coastal Policy Statement (NZCPS) set objectives and policies for regional councils to improve the integrated management of freshwater and the use and development of land. Furthermore, the Freshwater NPS is aimed at ensuring freshwater quality improves over time. The Government has set a national target that 90% of specified rivers and lakes are to be safe for primary contact by 2040.

The NZCPS is a national policy statement under the RMA that sets out the state policies to achieve the RMA purposes in relation to the coastal environment of New Zealand.

The Freshwater NPS also sets national bottom lines for water quality. The bottom lines are a minimum standard where Iwi and communities, through councils, decide how and when freshwater should be improved to these standards.

2.2 REGIONAL PLAN

Regional plans assist the regional council in carrying out its functions in accordance with the Resource Management Act. A regional plan provides objectives, policies, requirements and standards for stormwater management to be implemented within each region. The Auckland Unitary Plan Operative in Part (AUP OiP) and Waikato Regional Plan are the regional plans to be implemented within Auckland and Waikato Regions.

2.2.1 AUCKLAND UNITARY PLAN OPERATIVE IN PART

The AUP OiP, contains policies and methods to manage stormwater with respect to protecting public health and safety and to prevent or minimise adverse effects of contaminants on freshwater and coastal water quality. The best practicable option for every stormwater diversion and discharge is to be adopted.

The AUP OiP contains additional controls which are to be applied for sites identified in the Stormwater management area control – Flow 1 and Flow 2 in order to protect and enhance Auckland's rivers, streams and aquatic biodiversity in urban areas.

2.2.2 WAIKATO REGIONAL PLAN

The Waikato Regional Plan contains policies and methods to manage the natural and physical resources of the Waikato region so that activities that do not have more than minor adverse environmental effects are allowed to occur; and activities that have more than minor adverse environmental effects are managed to avoid, remedy, or mitigate those adverse effects.

2.3 INTEGRATED CATCHMENT MANAGEMENT PLAN

Under the national policies and regional plans, integrated catchment management plans (ICMP) are guidelines to manage water resources and land use on a catchment scale.

For example, the Rotokauri catchment is considered highly valued for its existing natural areas. The current land use is predominantly "greenfield". Under the Rotokauri ICMP, new stormwater management in the catchment is required to accommodate growth in an integrated manner and in accordance with proposed new land-uses.

Stormwater management within the Rotokauri catchment is to be designed, constructed, operated and maintained to minimize temperature fluctuation in receiving water bodies, maximize contaminant removal efficiencies at all times, be resilient to accidental contaminant spill and discharge and meet or exceed the stormwater treatment for the catchment including >70% total phosphorous removal prior to discharge to the receiving environment.

3 RAINGARDENS DESIGN METHODOLOGY

Bioretention is a stormwater management practice where runoff is filtered through a vegetated filter bed made of natural soil or engineered media. It improves water quality and is designed to achieve retention (via infiltration and evapotranspiration) and detention (slow release) of stormwater runoff. In most situations, raingardens are directly connected to impervious surfaces.

3.1 RAINGARDEN TYPE

The typical components of bioretention raingardens includes a ponding area, mulch layer, media, transition layer, drainage layer, an underdrain, retention layer (optional) and planting. The typical raingarden cross-section is illustrated in Figure 1.

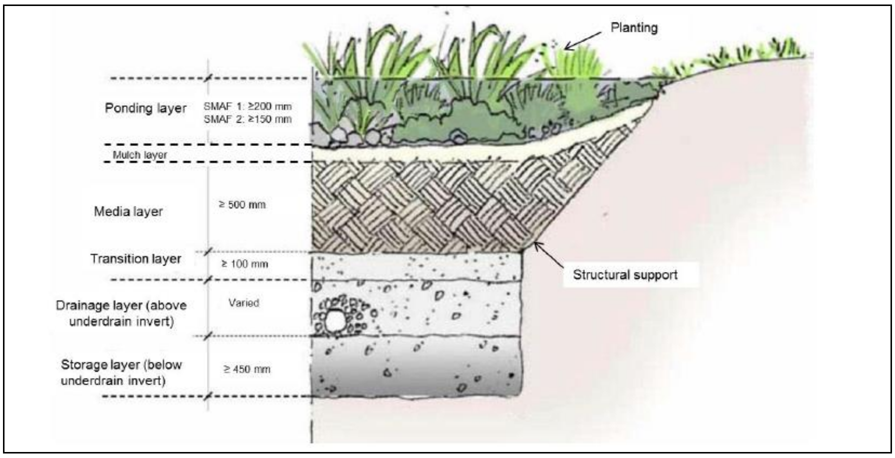

Figure 1: Typical Raingarden Cross-section, (GD01)

There are a few other raingarden configurations that can also be adopted. The following raingarden configurations are listed in the CRC water sensitive cities' Adoption Guidelines for Stormwater Biofiltration System.

- Unlined Biofiltration system with raised outlet
- Lined Biofiltration system with raised outlet
- Partially unlined Biofiltration system with raised outlet and lined submerged zone
- Bio-infiltration system with both lined and unlined cells

3.2 DESIGN APPROACH

The size of a bioretention raingarden may vary according to the functions it performs. However, for a given function, there are several different design guidelines depending on the specific region where the project is located. These guidelines give different sizes and layout requirements, potentially resulting in different outcomes and varying degrees of effectiveness.

In Auckland, the size of a bioretention raingarden is to be designed in accordance with Stormwater Management Devices in the Auckland Region, Guideline Document 2017/001 Version1 (GD01) which supersedes the Auckland City Council Technical Publication 10 (TP10). In Waikato region, the size of bioretention raingarden is to be sized in accordance with Auckland City Council Technical Publication 10 or similar.

Auckland Council, GD01

For a water quality treatment type of Raingarden, the size is to be designed as per equation 13 of the GD01, so that the device can pass the WQF of 10 mm/hr (equivalent of 90% of annual rainfall). The size of the bioretention area is a function of the runoff generated from the drainage catchment, and the infiltration of the bioretention media. The following equation is given for rain garden area calculation in GD01.

$$A = \frac{WQF}{(0.5 \times K_{(media)})} \qquad \text{Equation 13}$$

Where	A	-	Area of bioretention media bed at its narrowest point (m^2)
	WQF	-	Water quality flow (m^3/hr)
	$K_{(media)}$	-	Infiltration rate of bioretention media (m/hr)
	Safety factor for clogging	-	0.5

Figure 2: Bioretention Raingarden, Equation 13 (GD01)

To achieve retention and detention purposes, the size of the raingarden is to be designed as a function of the volume of runoff stored in storage layer, the volume of runoff that will infiltrate over 72 hours from the storage layer and the volume of runoff that will evaporate over 72 hours. The following equation is given for the raingarden area calculation in GD01.

$$V_{(detention)} = V_{(ponding)} + V_{(media)} + V_{(drainage)} \qquad \text{Equation 8}$$

Figure 3: Bioretention Raingarden Detention Requirements, Equation 8 (GD01)

$$V_{(retention)} = V_{(infiltration)} + V_{(evapotranspiration)} \qquad \text{Equation 12}$$

Figure 4: Bioretention Raingarden Retention Requirements, Equation 12(GD01)

<u>TP10/NZTA Stormwater Treatment Standard</u>

Under TP10 and NZTA Stormwater Treatment Standard for State Highway Infrastructure, the volumematric approach is adopted. The size of the bioretention area is a function of the runoff generated from the drainage catchment, the planting soil depth, the coefficient of permeability, the average height of water above the planting soil. The following equation is given for rain garden area calculation in TP10.

$$A_f = \frac{(WQV)(d_f)}{k(h+d_f)(t_f)}$$

A_f	= surface area (m^2)
WQV	= treatment volume (m^3)
d_f	= planting soil depth (m)
k	= coefficient of permeability (m/day)
h	= average height of water (m) = ½ max. depth
t_f	= time to pass WQV through soil bed (use one day to be conservative)

Figure 5: Bioretention Raingarden, TP10/NZTA

Adoption Guidelines for Stormwater Biofiltration Systems, CRC Water Sensitive Cities (CRC)

Under the CRC water sensitive cities Stormwater Biofiltration system, with Melbourne type climate, a typical biofiltration raingarden is recommended to have a minimum surface area of 2% of the impervious area of the contributing impervious catchment. With Brisbane type climate the biofiltration raingarden is recommended to have a minimum surface area of 4% of the impervious area of the contributing impervious catchment. Raingardens will need a ponding depth of 100 – 300 mm and a hydraulic conductivity of 100 – 300 mm/hr to meet regulatory load reduction targets for a temperate climate.

4 RAINGARDEN APPLICATION

Raingardens can be applied at source to target specific containment or applied centralized to treatment containments from the receiving catchment.

An at-source Raingarden is generally designed to be offline to the peak flows for large storm events and is usually sized to fit within the space available (such as within the road berm). At-source raingardens can target specific containments, and achieve retention and detention requirements with modified media. Access for safe and practical maintenance is generally available due to their location (e.g. roadside berms).

Figure 6: At source Bioretention Raingarden

Centralized raingardens in general are often designed for water quality purposes only for the contributing catchment. Peak flow attenuation for large events can be achieved above the raingarden media, however this approach is not recommend as the runoff from large stormwater events likely to re-suspend the accumulated containments and could result in erosion/scour of the raingarden media.

Furthermore, access for safe and practical maintenance for centralized raingardens needs to be incorporated as part of raingarden and land development design and is often constrained by competing land needs.

Figure 7: Central Bioretention Raingarden

5 CONSTRUCTION CHALLENGES AND DESIGN INFLUENCE

From design to construction, challenges encountered during the construction phase for projects in the Waikato and the Auckland Region is discussed in following sections.

5.1 DESIGN TO TARGET SPECIFIC POLLUTANTS

The bioretention raingarden size is governed by the water quality volume or the water quality flow from the contributing catchment.

The performance of a raingarden will depend on the characteristics of the contributing catchment and the condition of the receiving environment. The contaminant load from a high use road will be different to the contaminant load from a residential area. In general, from highest to lowest, the order of contaminant production from different catchments is industrial and commercial, motorway, higher density residential, lower density residential, farm land and forest. It is also to be noted that the loading for individual contaminants also varies depending on the land use. Stormwater runoff from these different catchments types needs to be managed differently to achieve the required design outcome.

Table 4-4
Contaminant loading ranges for various land uses
Figures are in kg/ha/yr except for FC (no./ha/yr)

Land use	TSS	TP	TN	Pb (median)	Zn	Cu	FC	COD
Road	281-723	.59-1.5	1.3-3.5	.49-1.1	.18-.45	.03-.09	1.8E+08	112-289
Commercial	242-1369	.69-.91	1.6-8.8	1.6-4.7	1.7-4.9	1.1-3.2	5.6E+09	306-1728
Residential (low)	60-340	.46-.64	3.3-4.7	.03-.09	.07-.20	.09-.27	9.3E+09	NA
Residential (high)	97-547	.54-.76	4.0-5.6	.05-.15	.11-.33	.15-.45	1.5E+10	NA
Terraced	133-755	.59-.81	4.7-6.6	.35-1.05	.17-.51	.17-.34	2.1E+10	100-566
Bush	26-146	.10-.13	1.1-2.8	.01-.03	.01-.03	.02-.03	4.0E+09	NA
Grass	80-588	.01-.25	1.2-7.1	.03-.10	.02-.17	.02-.04	1.6E+10	NA
Pasture	103-583	.01-.25	1.2-7.1	.004-.015	.02-.17	.02-.04	1.6E+10	NA

Figure 8: Contaminant loading for various land use

As an example, if the downstream receiving catchment is highly sensitive to nitrogen (N), then targeting TN from residential subcatchments is more criterial than targeting TN from the road subcatchments. The N removal rate is dependent on the plant take up and microbial functions within the raingarden. Therefore, the choice of plant species is important for N removal. Plant species with extensive and fine root systems will maximize uptake capacity and contaminant contact and are therefore critical for N removal. Selected species with extensive root systems will also effectively take up Phosphorus, a contaminant of concern in many receiving environments.

5.2 HIGH WATER TABLE

Installation of raingardens on sites with a high water table can be challenging as dewatering is often required during construction. The bedding of raingarden surrounds needs to be installed and compacted for the raingarden stabilization, which can be difficult in saturated soil conditions.

For sites with high groundwater, the depth of the raingarden media needs to be modified and a siphon drainage coil may need to be installed to prevent groundwater drawdowns to the adjacent stormwater network.

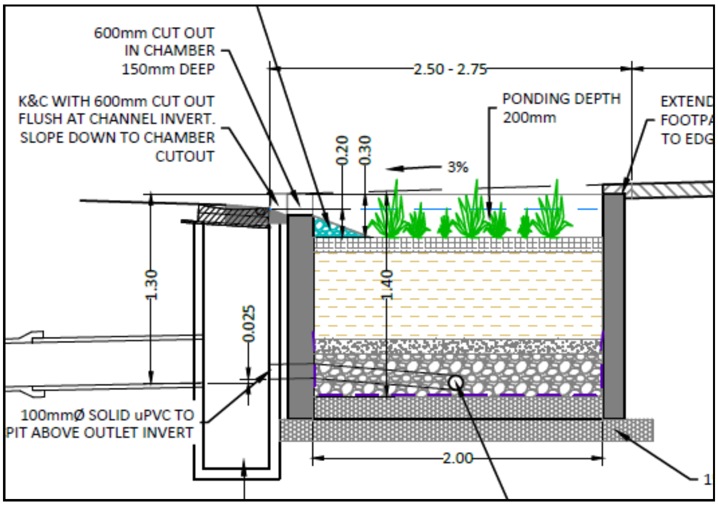

Figure 9: Typical raingarden with high groundwater table

5.3 RAINGARDEN MEDIA

The application of organic mulch will suppress weeds, retain soil moisture, protect soils from foot traffic, and break down over time to enhance organic content in topsoil.

The field evaluation undertaken by the Auckland Regional Council (ARC) for 41 raingardens from 30 sites in the Auckland region in 2006 identified erosion in a large proportion of raingardens with minimum mulch cover and with a mulch layer greater than 75mm, as mulch could potentially float[1]. The floating mulches could potentially clog the outlet structure causing further nuisance and flow bypass. In the Melbourne region, the use of mulch is not recommended in stormwater filters as the organic mulches are at risk of floating and clogging outlets according to CRC's adoption guidelines for stormwater Biofiltration systems.

Application of mulch within raingardens is considered to be common practice in majority of the regions in New Zealand. To prevent mulch floatation, the mulch should be applied at the depth between 50mm to 75mm[2]. Non-floating mulch should be specified and adopted for raingardens to prevent floating. The non-floating mulch can be sourced off the shelf.

Figure 10: Floating Mulch

Furthermore, the raingarden media depth should be at least 500mm-600mm to support the plant growth. However, where nitrogen is the primary pollutant 900mm of raingarden media is preferred (Christchurch Raingarden Guideline).

The infiltration requirements are different under various guidelines, under GD01 the infiltration rate of media should be between 50-300mm/hr for retention, detention and water quality treatment purposes. For water quality treatment only, the infiltration rate of media should be between 50-1000mm/hr. In the Christchurch Region the initial infiltration rate of media should be between 50-150mm/hr. Off the shelf products can be

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[1] Evaluation of Raingardens in Auckland Region, Rajika Jayaratne, Mike Martindale, Matthew D. Davis, Mike Timperley, Judy Ann-Ansen

[2] GD01 Table 48

sourced with the infiltration rate between 100-300mm/hr and meet most of the design requirements. With a low media infiltration rate, overflow from the raingarden is likely to occur frequently and will therefore not achieve the treatment requirements.

Figure 11: Overflow from Raingarden

5.4 RAINGARDEN INLET

Erosion at raingarden inlets is often observed onsite due to the concentrated flow. Inlet erosion could be mitigated or prevented with application of a riprap apron or coconut mat etc. However if the riprap apron is not properly size or installed, the riprap is likely to be washed away by the concentrated runoff and result in raingarden erosion as shown in Figure 12.

Figure 12: Erosion at raingarden inlet

Inlet sediment build-up could be encountered for flat areas. To promote the stormwater runoff entering a raingarden, no obstruction or riprap should be install above the adjacent kerb and channel invert level. With riprap install above the adjacent kerb and channel, sediment could easily accumulate and wash into the adjacent cesspit, and hence reduce the raingarden’s treatment capability.

Figure 13: Accumulated sediment at raingarden inlet

5.5 RAINGARDENS IN ROAD CORRIDORS

Pre-cast raingarden surrounds are a precast concrete structure to contain treatment media and vegetation. They often are used within the road berms, road centre medians and car parks. They are designed to be fitted within the road berm and withstand adjacent vehicle loading.

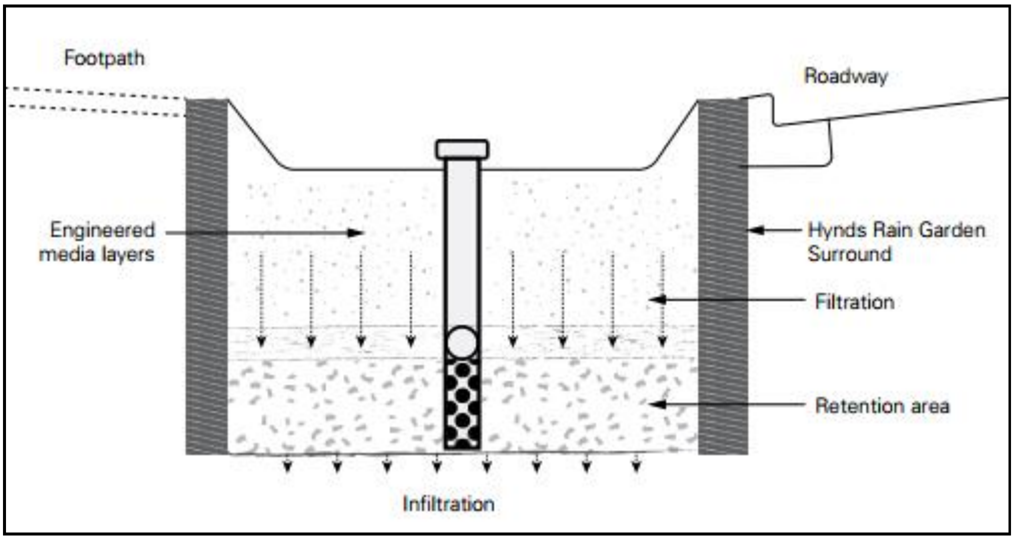

Figure 14: Hynds Pre-cast raingarden surround

The raingarden construction methodology for road application summarised below was completed in consultation with contractors. The precast raingarden surround can be installed either prior or after the kerb and channel construction.

Post Kerb and Channel Formation

Raingardens were constructed post kerb and channel formation at one of CKL's site at Rotokauri, Hamilton. Carriageways, berms, footpaths and associated carparks were installed prior to the raingardens. Prior to installation, trenches were prepared adjacent to the kerb and the channel for the raingarden surround.

It was noticed onsite that:

- The kerb needed to be cut out at the raingarden entrances
- Kerbs and channels could be damaged during the surround installation
- Gaps between the kerb and channels and the raingardens are hard to avoid
- Subgrade collapsed adjacent to the raingarden surround

The following approaches were adopted to resolve the problems:

- fill the gaps with concrete
- replace damaged kerbs and pavement
- Allow 500mm berm between raingarden and kerb and channel

Figure 15: As-built pre-cast raingarden surround

Prior to Kerb and Channel Formation

Raingardens were constructed prior kerb and channel formation. Carriageway, berm, footpath and associated carpark required to be positioned prior to the raingarden.

If raingarden surround is laid prior to the kerb and channel:

- kerb machine cannot be used
- raingardens need to be set-out and installed precisely
- depending on the number of raingardens, hand placed kerbs are not always possible
- inconsistency between the hand placed and machine laid kerbs and channels

The following approaches could be adopted to overcome these issues:

- pin kerb above the raingarden surround
- Allow 500mm berm between raingarden and kerb and channel

Figure 16: Kerb and Channel above raingarden surround

Adjacent to curved kerb and channel

To install a raingarden adjacent to the curved kerb and channel, the raingarden must be installed parallel to the kerb and channel. The gap between each raingarden surrounds and the adjacent kerb and channel needs to be filled with concrete.

Figure 17: Concrete fill between raingarden surrounds

<u>For roads with steep longitudinal gradient.</u>

The raingarden could be installed in steps or laid with an angle.

Where the raingarden is installed at an angle that matches the road longitudinal gradient, the sub grade needs to be prepared at an angle and the foot of the raingarden surround needs to be set on concrete to prevent settlement. The raingarden media and other layers need to be laid flat. Contractors need to have knowledge to install raingardens correctly. However, the total depth provided within the raingarden surround will be sacrificed to achieve the longitudinal road gradient.

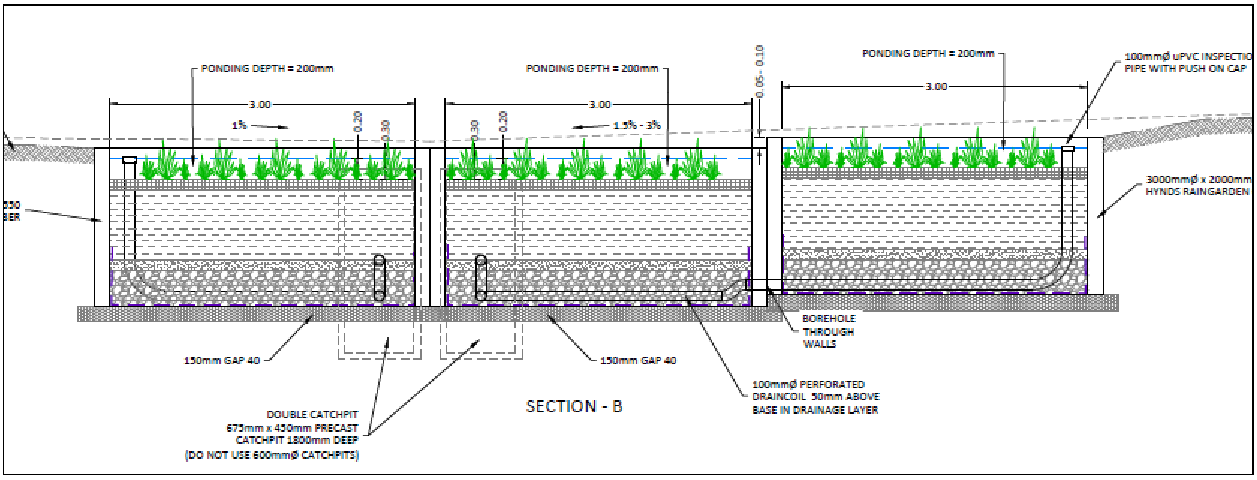

Figure 18: Raingardens installed in steps

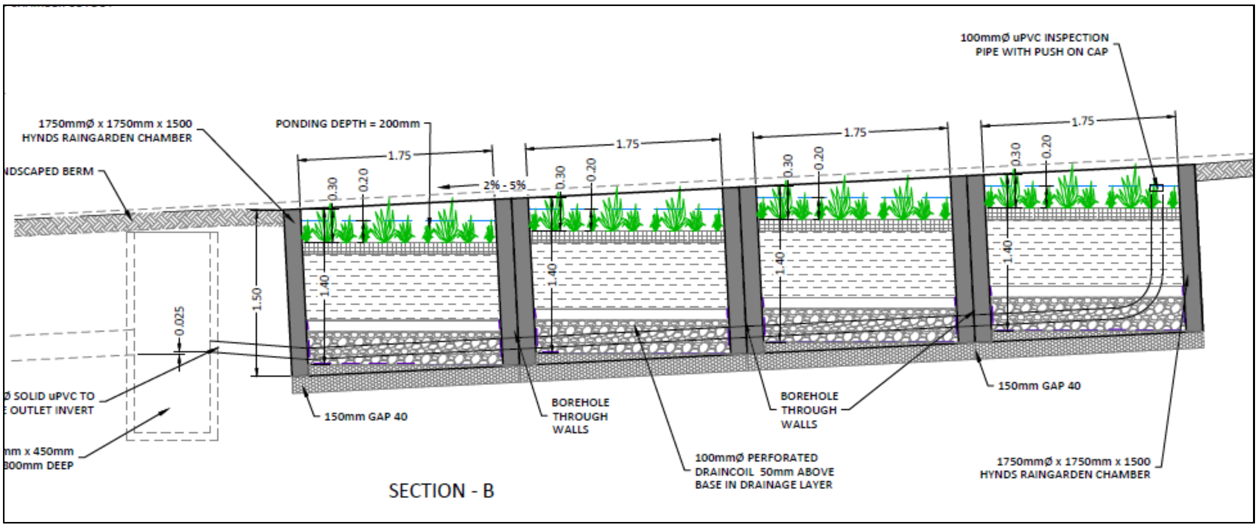

Figure 19: Raingarden installed at an angle

5.6 PLANT SELECTION

Raingarden plants are selected by the landscape architect or the engineer and installed by the onsite contractor. Trees should not be placed in raingardens unless they were specified.

Figure 20: Raingarden with palms tree planted

5.7 RAINGARDEN MAINTENANCE

The raingardens need to be maintained properly to function. Sediment deposition, erosion and scour, litter removal, plants maintenance, weed removal are to be done every 3 months. The underdrain and water level in the submerged zone has to be maintained annually.

Raingarden plants will be overtaken by weeds if not maintained as shown in Figure 21.

Figure 21: Unmaintained Raingarden

6 CONCLUSION

Raingardens are considered a water sensitive stormwater management device for contaminant removal and meeting the regulatory obligations. For several projects in both the Waikato and the Auckland Region, challenges from design to built are considered not only an iterative process but also provide opportunities to achieve better design and better outcomes.

REFERENCES

Auckland Regional Council (ARC). 2003 TP10 –Stormwater Management Devices Design Guideline Manual 2003.

Auckland Council (AC). 2017 GD01 Version 1 – Stormwater Management Devices in the Auckland Region

Christchurch City Council (CCC). 2016 – Rain garden design, construction and maintenance manual

Cooperative Research Centre for Water Sensitive Cities (CRC). 2015 – Adoption Guidelines for Stormwater Biofiltration System

Hamilton City Council (HCC). 2016 – ITS Section 4 –Stormwater

Hamilton City Council (HCC). 2017 - Rotokauri Integrated Catchment Management Plan

Jayaratne, R. Martindale, M. Davis, M.D. Timperley, M. 2010 -Evaluation of Rain Gardens in Auckland Region. Water New Zealand Stormwater Conference 2010

NZ Transport Agency (NZTA). 2010 - Stormwater Treatment Standard for State Highway Infrastructure