OPTIMISING RAIN GARDEN, TREE PIT AND PROPRIETARY FILTRATION DESIGN FOR CHRISTCHURCH

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ABSTRACT

Christchurch City Council is developing a Stormwater Management Plan for the Avon-Ōtakaro, a highly urbanised catchment of 8,860 hectares. As few sites exist for large treatment devices, retrofitting smaller treatment devices into the existing network is one of the main mitigation options available. Rain gardens, tree pits and proprietary filters have all been identified as potential options suitable for retrofit water quality treatment.

Since design of these devices is highly climate dependent, this study developed a method allowing commonly used design parameters to be assessed against the historic Christchurch 30 minute rainfall record (1963-2013). The aim was to determine the optimum configuration (lowest cost versus treatment capability) by: establishing design parameters based on international and local design best practice; modelling the design parameters against the rainfall record to ensure greater than 80% volume capture and equivalence with other treatment devices; and developing a cost model to arrive at the most efficient design. Significant savings are predicted through optimising the selection and design process.

This paper summarises recent assessments of hydrologic design criteria of these devices undertaken on behalf of Christchurch City Council.

KEYWORDS

Rain garden, stormwater tree pit, bioretention, treatment, rainfall

PRESENTER PROFILE

Peter Christensen is a Surface Water Engineer with Aurecon and is based in Christchurch. He has a wide range of experience in surface drainage issues, including surface water modelling, stormwater treatment design and consenting.

1 INTRODUCTION

Christchurch City Council (CCC) is developing a Stormwater Management Plan for the Avon River, a highly urbanised catchment of 8,860 hectares. As few sites exist for large treatment devices, retrofitting smaller treatment devices into the existing network is one of the main mitigation options available. Rain gardens, tree pits and proprietary filters have all been identified as potential options suitable for retrofit water quality treatment.

The sizing of these stormwater treatment devices is highly climate dependent, but in Christchurch these devices are usually designed with information adopted from other climates and sometimes using parameters derived for other treatment devices. This study determined Christchurch specific design parameters using the historic Botanic Gardens 30 minute rainfall record (1963-2013) as the assessment base.

The aim was to investigate the optimum design parameters to ensure treatment equivalence with other devices used in Christchurch. The study focused on two different groups of devices considered suitable for retrofitting in Christchurch. The first was bioretention (or biofiltration) devices, in particular rain gardens and stormwater tree pits. Both were sized using a similar methodology. For the purposes of this paper they will generally be referred to as 'bioretention devices'. The second group is proprietary filtration devices (PFDs). The StormFilter was the device reviewed but the findings apply to all in-line filtration devices.

2 DEVICES ANALYSED

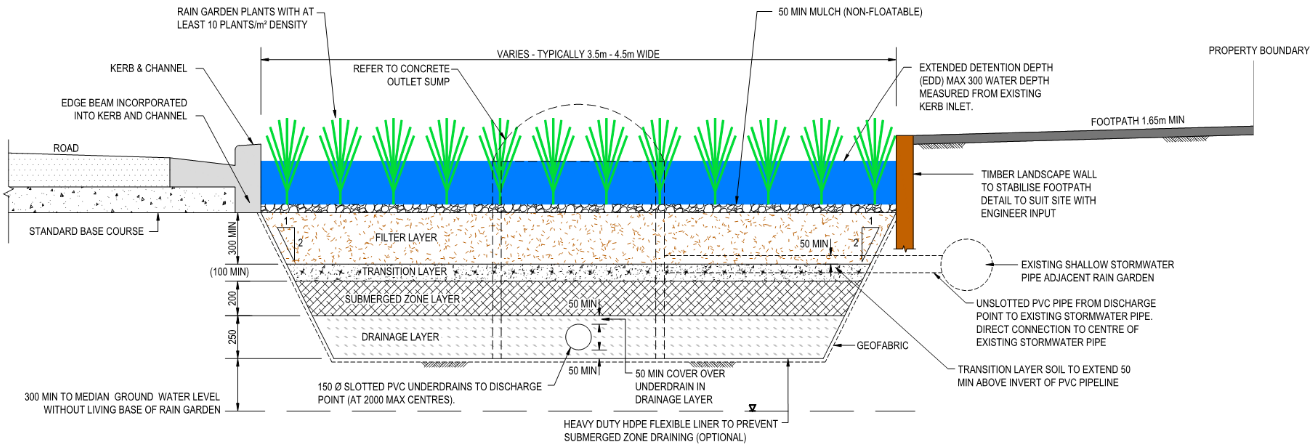
2.1 RAIN GARDENS

Rain gardens are planted stormwater treatment devices which contain a deep layer of filtration media (as opposed to a shallow layer such as infiltration basins). However, they are also referred to as bioretention or biofiltration devices.

Christensen (2014) worked with CCC staff to develop design guidelines and standard details of rain gardens for Christchurch. One of the typical details developed is shown in Figure 1 below. This shows the key design variables of the extended detention depth (EDD), the filtration media, and also the underdrain configuration (the detail shown is for a rain garden with a saturated zone at the base).

At present there is no Christchurch specific design standard for rain gardens (or tree pits) and this study aimed to develop guidelines appropriate to Christchurch conditions.

Figure 1: Rain Garden Schematic

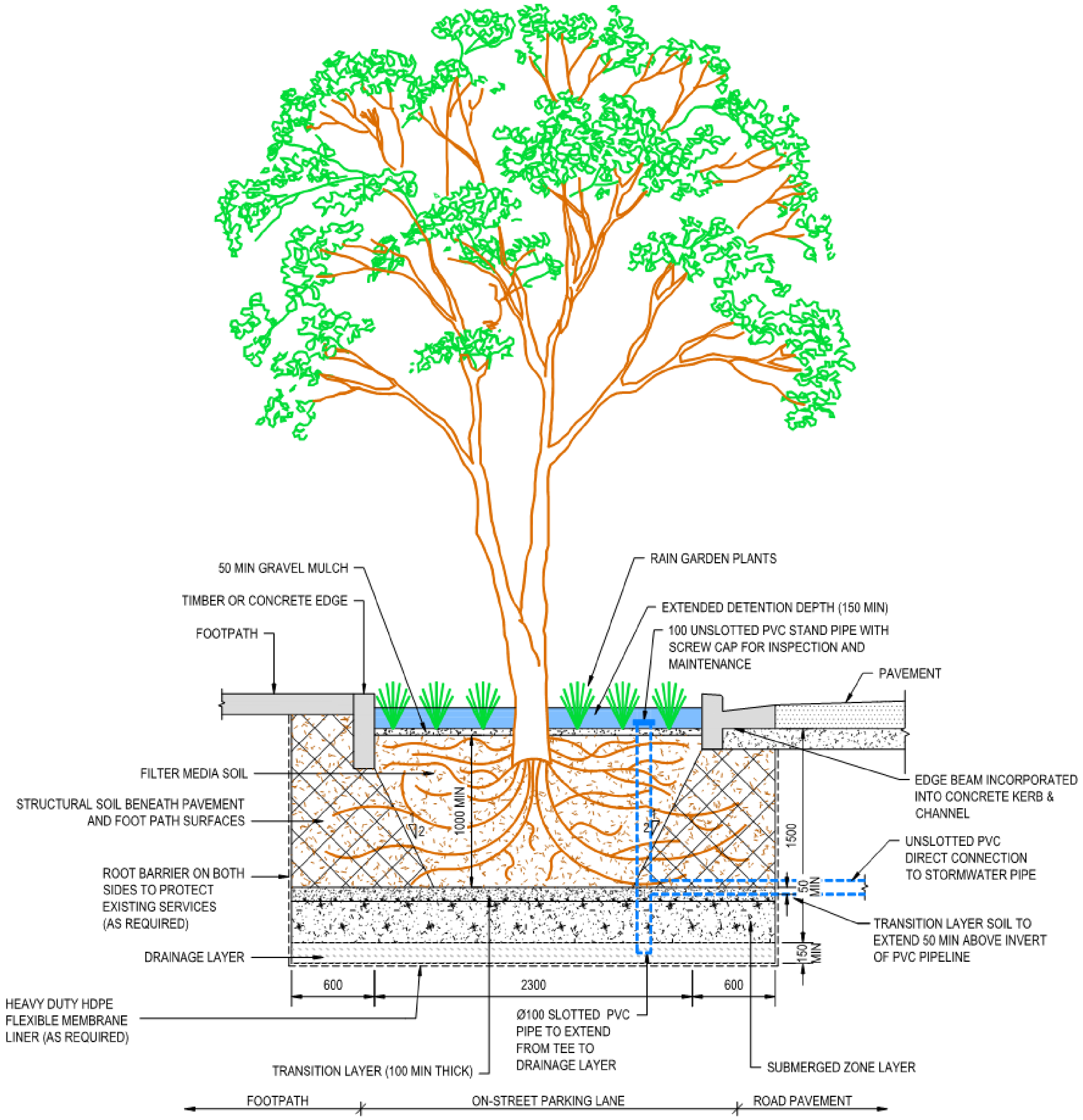


2.2 STORMWATER TREE PITS

Stormwater tree pits are a versatile bioretention stormwater management device providing passive irrigation of street trees, stormwater quality treatment and also peak flow and volume attenuation. Other stormwater management benefits include increased canopy interception, evapotranspiration and infiltration. These all result in a reduction in the magnitude and frequency of stormwater runoff, and hence a reduction in pollutant loads entering receiving waterways. Significant non-stormwater benefits are also provided.

Stone (2014) worked with CCC staff to develop design guidelines and details for stormwater tree pits in Christchurch. This work built on that undertaken for rain gardnes but began with the requirement for sufficient soil volume for a healthy and long living tree. This was determined in consulation with a CCC arborist and review of international practice to be 3.5 m square with a depth of soil of at least 1.0 m. The typical detail developed for a stormwater tree pit in shown in Figure 2.

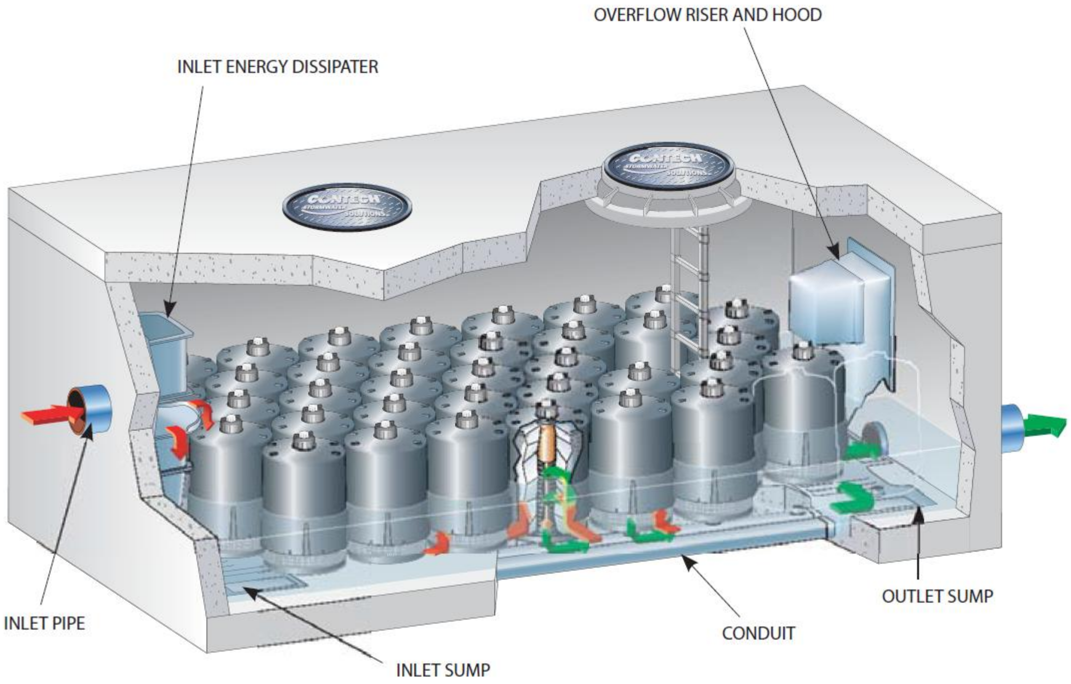
Figure 2: Stormwater Tree Pit Schematic



2.3 PROPRIETARY FILTRATION DEVICES (PFD)

In-line filtration devices can take a number of forms but typically they have a base flow treatment rate with an overflow mechanism (Figure 1). Proprietary devices were assessed for Christchurch City Council by Parsons (2013).

Figure 1: StormFilter proprietary filtration device (replicated from Stormwater 360 brochure, 2007)



Auckland Council recently undertook a study to develop a design rainfall intensity for PFDs to inform the Auckland Unitary Plan (pers. comms., Nick Vigar to Tom Parsons 6 August 2013). They used a very similar analysis as undertaken in this paper but used 11 rain gauge records. The derived design intensity for their region was approximately 10 mm/hr. This figure has been used to size PFDs in Christchurch but it was recognised that there was a need to determine the appropriate figure for Christchurch which was expected to be somewhat less than that arrived at for Auckland climatic conditions.

3 STUDY METHODOLOGY

3.1 DETERMINE ASSESSMENT CRITERIA

The first requirement of the study was to determine the assessment criteria for evaluating the devices. Two assessment criteria were used: hydrologic treatment equivalence with existing devices used in Christchurch; and cost optimisation within the bounds of treatment equivalence.

3.1.1 HYDROLOGIC TREATMENT EQUIVALENCE

Bioretention devices sizing is a factor of both runoff volume and rainfall intensity. PFDs are sized purely based on rainfall intensity. The primary CCC stormwater design guideline, the *Waterways, Wetlands and Drainage Guide* ('WWDG') (CCC, 2003) adopts the approach of treating the 'first flush' runoff from a catchment, and has methods for calculating the first flush volume based on a particular depth of rainfall. The first flush volume used in Christchurch is equivalent to the water quality volume used in other locations. However, a purely volume based approach is not applicable to either bioretention devices or PFDs and therefore a methodology was needed to help determine hydrologic treatment equivalence.

The first flush depth of 25 mm reported in WWDG is based on an assessment of historic Christchurch rainfall depths to determine the depth required to capture 80% of the runoff. This is based on a general rule that capturing 80% of the runoff volume results in capture of 75% of the total suspended sediment (e.g. ARC TP10 (ARC, 2003)). Figure 4 below is reproduced from WWDG and illustrates this analysis.

Figure 4: Waterways, Wetlands and Drainage Guide (CCC, 2003) First Flush Capture

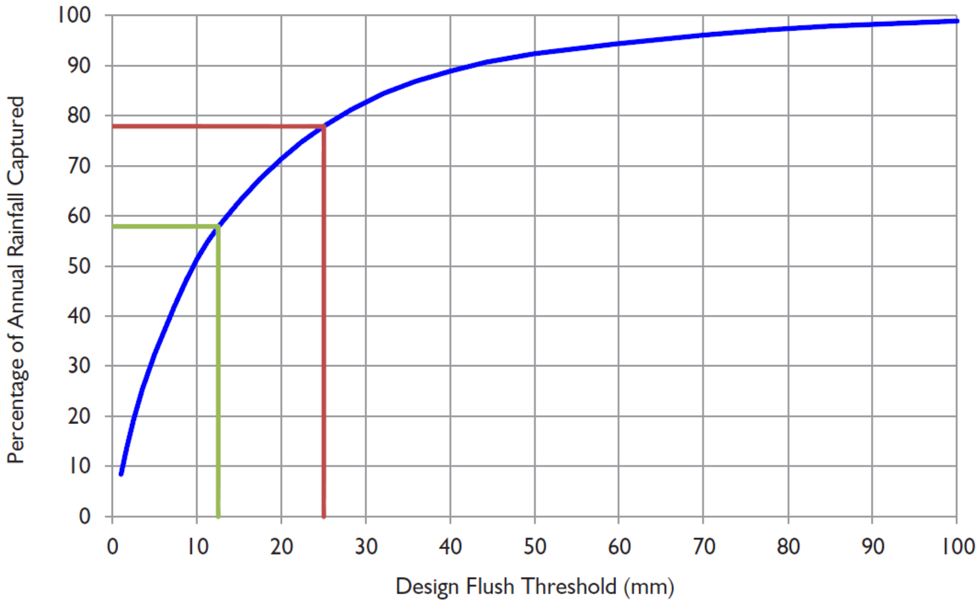


Figure 6-4: Botanic Gardens rain gauge percentage of annual rainfall captured for design flush depth. The highlight lines show 58% capture for a rain depth threshold of 12.5mm and 78% capture for a 25mm threshold.

Although it is recognised that the treatment characteristics of the proposed and existing devices were different, this study was focused on hydrologic equivalence (e.g. capturing the same runoff volume) of the devices, recognising that at a later stage it would be necessary to assess the capability of the various devices to treat the contaminants contained within that runoff volume. Therefore it was decided that treatment of 80% of the runoff volume was an acceptable measure for determining hydrologic treatment equivalence of the devices.

3.1.2 COST ASSESSMENT

A cost model was developed for bioretention devices to determine the lowest cost configuration which still provided treatment of 80% of the runoff volume. This was necessary because several design criteria can be modified while still achieving 80% volume capture. Therefore the optimum configuration could only be determined by calculating the capital cost of each of these modifications (within the bounds of acceptable international practice).

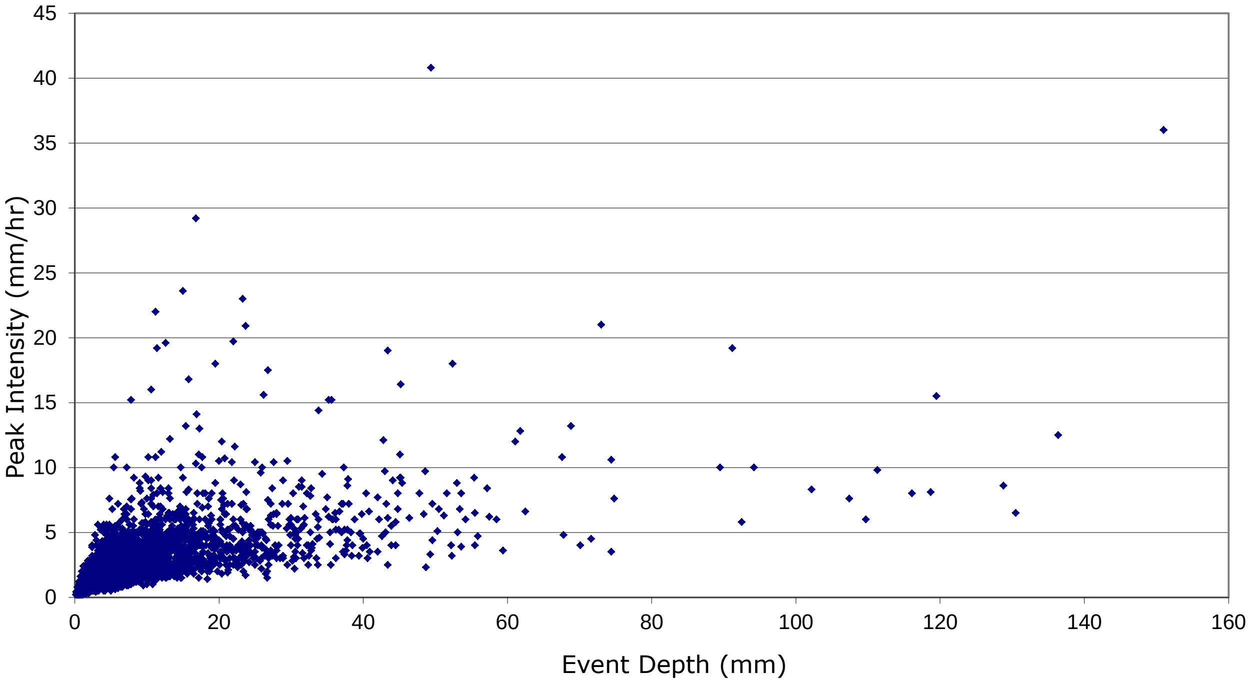
A cost model was not developed for PFDs as there was only one factor being varied and therefore no optimisation was possible.

3.2 DEVELOP HYDROLOGIC MODELS TO ASSESS PERFORMANCE

In order to determine hydrologic treatment equivalence it was necessary to construct simple hydrologic models of the devices to assess this. The Christchurch Botanic Gardens weather station has a 30 minute interval rainfall record dating back to January 1963 (approximately 50 years of record). This data series was used to construct continuous simulation models of bioretention devices and PFDs to determine treatment of 80% of the runoff volume. This is similar to the methodology used to determine the first flush depth in WWDG and therefore provided more assurance of commonality with the existing criteria. This method is also similar to that recently used by Auckland Council to determine the design rainfall intensity to inform the Auckland Unitary Plan (pers. comms., Nick Vigar to Tom Parsons 6 August 2013).

Figure 5 shows the intensity versus event depth for the entire record (assuming a 2 hour inter-event period).

Figure 5: Botanical Gardens Rainfall Record



It should be noted that the results presented in this paper are only relevant for those parts of Christchurch with similar rainfall characteristics as the Botanical Gardens site and should not be used elsewhere without suitable modification.

The methodology followed for developing the hydrologic models for the devices was as follows:

1. Import the 30 minute Botanic Gardens rainfall record dating back to January 1963 (approximately 50 years of record)

2. Create a simplistic spreadsheet-based water balance model of the devices for each record assuming a constant inflow during the 30 minute record

3. Modify key design variables (e.g. intensity prior to bypass for PFDs and infiltration rate etc for bioretention devices) until 80% of the entire rainfall record is treated through the device

For each device there were a number of scenarios tested and some of these are discussed in the results.

3.2.1 BIORETENTION DEVICE SIZING FORMULA

In order to model the hydrologic performance of the rain gardens and tree pits it was necessary to determine which sizing formula to use. Section 8.5.3.5 of the NZTA (2010) specification contains a rain garden sizing formula based on Darcy's law (and is one which can be found in various international literature as well). This was considered suitable for use in Christchurch and was modified to be consistent with WWDG terminology as follows:

$$A_{rg} = \frac{(V_{ff})(d_{rg})}{k(h+d_{rg})t_{rg}} \qquad (1)$$

Where:

A_{rg} = filtration area of bioretention device (m^2)

V_{ff} = first flush or first flush volume (m^3) – determined as per Equation 6-2 in WWDG

d_{rg} = filter depth (m)

k = coefficient of permeability (m/day)

h = average height of water (m) = ½ extended detention depth (EDD)

t_{rg} = time to pass V_{ff} through soil bed

Equation (1) calculates the surface area of a bioretention device. In addition there needs to be control over the minimum size of the bioretention device. This prevents under sizing of bioretention devices through the use of excessively high infiltration rates and shallow beds which would result in less than 80% annual volume capture through not providing sufficient storage.

NZTA (2010) achieves this by requiring the above ground storage to be at least 40% of the V_{ff}. This approach was tested as a variable in the analysis and the conclusion was that it proved to be a necessary control. Therefore a minimum bioretention device size is to be calculated using:

$$A_{EDD} \geq \frac{0.4 * V_{ff}}{(2 * h)} \qquad (2)$$

Where:

A_{EDD} = Extended detention (storage) area of bioretention device (m^2)

3.3 DETERMINE KEY DESIGN VARIABLES

3.3.1 RAIN GARDENS AND TREE PITS

The key variables affecting the hydrologic design aspect of bioretention devices are:

- First flush depth (which determines the water quality volume entering the device)
- Infiltration rate (through the filtration media)
- Filter media depth

All other factors were considered fixed, except that rain gardens had an extended detention depth of 0.3 m and stormwater tree pits had only 0.15 m. A shallower depth was used in stormwater tree pits to enable a wider range of tree species to be used and also because a shallower depth is more suitable to a highly trafficked CBD environment that they were envisaged to be used in.

The key variables were altered in the model to achieve 80% volume capture at the lowest cost while maintaining as much commonality as possible with parameters already used within the following guidelines:

- The primary CCC stormwater design guideline, the Waterways, Wetlands and Drainage Guide (CCC, 2003) – commonly referred to as 'WWDG'
- The New Zealand Transport Agency stormwater specification, Stormwater Treatment for Road Infrastructure, (NZTA, 2010) parameters

The process undertaken to select the infiltration rate and filter media depth warrant further discussion as the infiltration rates used are lower than those typically used internationally and the filter media depth is less than that used in NZTA.

BIORETENTION MEDIA INFILTRATION RATE

This is referred to as k or the coefficient of permeability (m/day) in Equation (1). For the purposes of this research it was considered identical with infiltration rate. Generally the infiltration rate needs to be in a range where it is low enough to facilitate the processes leading to pollutant removal, but high enough to be hydrologically efficient. Fassman et al (2013) reported a range of infiltration rates in international literature from 12.5 mm/hr up to 300 mm/hr. However the majority fell within the range from 12.5 mm/hr to 50 mm/hr, with the primary exception being the Australian based FAWB (2009) guidelines.

NZTA (2010) recommends a rate of 0.75 m/day. WWDG recommends a design infiltration rate of 20 mm/hr for soil adsorption basins. However, rain gardens differ from soil adsorption basins in that:

- They have a greater depth of imported media;
- Soil adsorption basins are typically only planted with grass, whereas the range of plants in a rain garden can maintain infiltration rates for longer; and
- Soil adsorption basins are often dual use, subject to foot traffic and mower vehicles which can compact soil and reduce infiltration rates over time.

As a result it is considered that a higher infiltration rate be adopted for rain gardens than that specified in WWDG for soil adsorption basins. However, one of the requirements was that the infiltration rate did not differ significantly from that used in WWDG or that used recommended in NZTA (2010) and so the infiltration rates tested were close to the rates used in these publications.

FILTER MEDIA DEPTH

Media depth is referred to as d_{rg} or planting soil depth (m) in Equation (1). The depth is usually determined by:

- Water quality objectives – different contaminants require different depths to be treated
- Planting requirements – trees require a greater depth than grasses for example. (However, for the plants likely to be used in rain garden in Christchurch this is unlikely to be a limiting factor and so will not be considered further in this study.)

- Hydrologic goals – deeper media provides greater attenuation and volume reduction while correspondingly reducing the overall infiltration rate (due to Darcy’s law)

While all these factors were considered, only the effect on water quality will be discussed here. Different contaminants are treated at different depths within a rain garden system. Hunt (2011) summarises the depth required which is reproduced in Table 1 below. Note that media depth and infiltration rate work together in pollutant removal, as the media depths below need to be considered in conjunction with infiltration rates.

Table 1 Minimum Media Depths for Water Quality Treatment (Hunt, 2011)

Pollutant	Depth (m)	References
TSS	0.3	Diblasi et al. 2009, Li et al. 2008
Metals	0.3	Li and Davis 2008, Hatt et al. 2009
Oils &Grease	0.3	Diblasi et al. 2009,
Pathogens	0.0	Hunt and Lord 2006
Phosphorus	0.6 (min) - 0.9 (conservative)	Hatt et al. 2009, Passeport et al. 2009
Nitrogen	0.9	Passeport et al. 2009
Temperature	0.9 (min) - 1.2 (optimum)	Jones and Hunt 2009

It was considered that a depth of 0.6 m provides good removal of TSS and metals, moderate removal of phosphorous, and some removal of nitrogen. This suited the contaminant removal priorities for the Avon River catchment.

3.3.2 PROPRIETARY FILTRATION DEVICES

PFDs are designed to an inlet flow rate based upon design rainfall intensity and catchment characteristics. Apart from the number and type of filtration cartridges they are not customizable, therefore the only design criteria reviewed was the design rainfall intensity.

4 RESULTS AND DISCUSSION

4.1 BIORETENTION DEVICES

4.1.1 80% VOLUME CAPTURE

80% volume capture by rain gardens and stormwater tree pits can be achieved through a number of combinations of the key variables. For example, increasing first flush depth and reducing the minimum volume capture can have the same result as decreasing first flush depth and increasing the minimum volume capture. Likewise the infiltration rate could be increased dramatically and the minimum storage volume reduced to still capture 80% of the volume.

To provide some bounds to the analysis the following guidelines were followed:

- Commonality of parameters with existing design standards
- Round numbers were favoured over other numbers that may have resulted in a slightly better optimisation because it was envisaged that these parameters would eventually be adopted as standard in Christchurch

- Lowest cost for equivalent volume capture should be achieved

A range of scenarios were tested and the results of some of these are presented in Table 2 below. Cost estimates are based on treating one impervious hectare.

It can be seen that combining the recommended parameters in WWDG with the NZTA formula (as is sometimes done in Christchurch) substantially oversized the devices. Likewise maintaining a first flush depth of 25 mm results in oversizing despite varying other parameters such as minimum storage volume, infiltration rate and filter media depth.

Table 2 Rain garden % volume capture using Christchurch Botanic Gardens rainfall record

Scenario	**First flush depth (mm)**	**Minimum V_{ff} storage**	**Filter media depth (m)**	**Infiltration rate (mm/hr)**	**Percent volume capture (%)**	**Rain garden area (m^2)**	**Cost per impervious hectare treated**
WWDG + NZTA	25.0	40%*	0.85*	20^{+}	90	444	$279,000
A	25.0	40%*	0.85*	31*	89	333	$215,000
B	25.0	0%	0.85*	31*	85	284	$198,000
C	25.0	40%	0.60	30	89	333	$197,000
NZTA	17.5*	40%*	0.85*	31*	80	233	$165,000
Optimum	**20.0**	**40%**	**0.60**	**30**	**83**	**267**	**$168,000**

In the table * represents NZTA design parameters and + WWDG design parameters.

The standard NZTA design achieves 80% capture which provides local validation of the NZTA design method. This is to be expected as it is derived from a similar analysis of long term rainfall records (although using the 90 %ile storm depth as the design standard (NZTA, 2010)). However, the optimised design provides a higher capture rate for a minimal cost increase. The often shallow groundwater depths in Christchurch also means a design with a shallower filter media would be more desirable. The 'optimum' design parameters are also more consistent with the parameters in WWDG.

A number of other scenarios were tested and some resulted in lower costs but were rejected as unsuitable for Christchurch conditions. For example:

- A higher infiltration rate results in higher percent volume capture for lower cost. However, anecdotal evidence suggested that this infiltration rate would be difficult to achieve and the 'optimum' design stays closer to the currently used 20 mm/hr for infiltration basins
- A shallower media depth resulted in savings but compromised treatment efficiency

Stormwater tree pits were analysed using a similar method as for rain gardens, with the exception that the extended detention depth used was 150 mm instead of 300 mm. This depth was chosen as it is considered more suitable for trees and city centre environments.

4.1.2 RECOMMENDED BIORETENTION DEVICE DESIGN PARAMETERS

The recommended design parameters for bioretention devices considered in this paper are given in Table 3 below:

Table 3: Bioretention Design Criteria for Christchurch

Design Criteria	Rain Garden	Stormwater Tree Pit
Rainfall depth for determining first flush volume	20 mm	
Design infiltration rate	30 mm/hr	
Media depth	0.6 m	1.0 m
Extended detention depth	0.3 m	0.15 m

4.2 PROPRIETARY FILTRATION DEVICES

4.2.1 DISCUSSION

As mentioned previously, Auckland Council recently undertook a similar study to develop a design rainfall intensity to inform the Auckland Unitary Plan (pers. comms., Nick Vigar to Tom Parsons 6 August 2013). They used a very similar analysis as undertaken to inform this paper but it was undertaken using 11 rain gauge records. The derived design intensity for the Auckland region was approximately 10 mm/hr and this analysis aimed to determine the appropriate design rainfall intensity for Christchurch below which 80% of the total runoff volume occurred.

Several scenarios with different design assumptions were analysed:

- For all records for all events (i.e. no modification)
- For all records with a cumulative event depth greater than 2.5 mm (to represent events with no runoff if a ponding depth of 2.5 mm was assumed)
- For all records with a cumulative event depth of less than 25 mm (to compare against the traditional volumetric design criteria).

Figure 6 shows the intensity records versus the normalised cumulative depth for the three depth scenarios described above. The blue line shows the base case with all intensities within the record analysed. The red line shows the all intensity records for a cumulative event depth of less than 25 mm. This shows a very similar shape to the red line, which indicates that high intensity records are not strongly related to time within the event. Excluding all intensities within events when the cumulative depth is less than the WWDG ponding depth of 2.5 mm (green line) excludes a large proportion of the record (approximately 45% of records) and results in a slightly steeper curve.

Figure 6: Normalised cumulative depth versus intensity

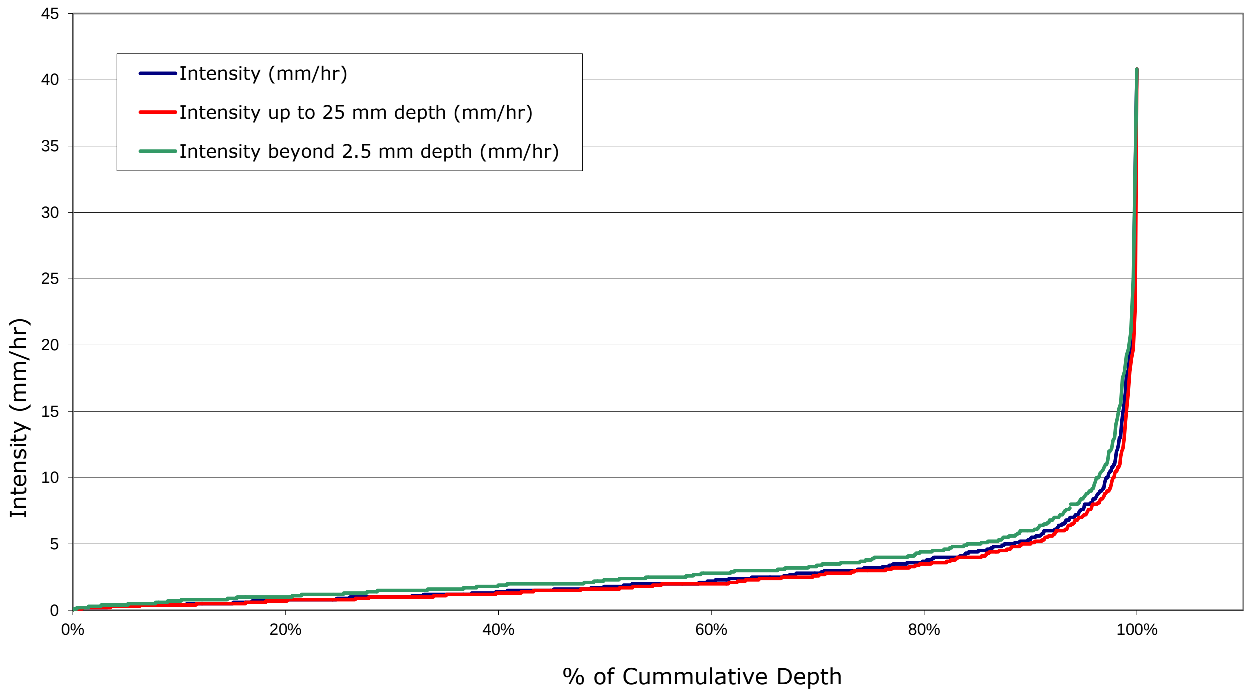


Table 4 summarises the range in design intensities for different capture percentages and scenarios. The results show that:

- A significant increase in design rainfall intensity is required to capture higher proportions of the total depth.
- Assumptions about ponding depths can significantly alter interpretation of the results.

Table 4: Design Intensity (mm/hr)

Rainfall	**80% capture**	**90% capture**	**95% capture**
All 30 minute records	2	3	4.5
Intensities within first 25 mm of event	2	3	4
2.5 mm minimum wash off depth	2.5	3.5	5

The analysis undertaken was relatively simplistic and assumed that the contaminant wash off is proportional to intensity. The concentrations of contaminants washed off during an event will vary by type, depth and intensity, as the mechanism for wash off of contaminants will vary. Some contaminants (such as sediment from pervious areas and zinc from roofing) may contribute through the entirety of the rainfall event, whereas others (such as hydrocarbons and lead from exhaust fumes) may wash off early in an event.

As this project has not attempted to assess the relationship between contaminant wash off and intensity, it was considered that a conservative intensity should be selected in order to achieve desired environmental outcomes. It can be seen from Table 3 that there is a wide range in results for a given capture rate depending on the design and wash-off assumptions.

4.2.2 RECOMMENDED DESIGN RAINFALL INTENSITY FOR PROPRIETARY FILTRATION DEVICES IN CHRISTCHURCH

Given the uncertainties with contaminant wash off and the relatively basic analytical approach taken a figure of 5 mm/hr was recommended for use in design of in-line filtration devices in applicable areas in Christchurch. A greater percentage of rainfall depth treatment could be achieved by increasing the design intensity above 5 mm/hr but the additional cost involved was not considered justified. Oversizing of devices results in little additional environmental benefit and reducing the design intensity from 10 mm/hr to 5 mm/hr results in substantial capital and operation cost savings.

It should be noted that the design rainfall intensity of 5 mm/hr only applies to areas with similar rainfall patterns to the Christchurch Botanical Gardens rain gauge. A similar analysis to the one described above could be taken for other areas to develop locally specific design rainfall intensity.

4.3 COMPARING HYDROLOGIC TREATMENT BETWEEN DEVICES

The PFD design criterion of 5 mm/hr rainfall intensity results in capture of more than 80% of the volume and hydrologic treatment equivalence with other devices was considered to be achieved as a result.

The design of soil adsorption basins in Christchurch is based purely on the volume required to capture the runoff from a rainfall depth of 25 mm. This is based on previous analysis which shows that the 78% of annual rainfall captured for a design first flush depth of 25 mm (as stated in WWDG).

However, because bioretention devices are designed using a combination of both volume (the extended detention depth) and flow (infiltration) further analysis was required to provide certainty about the equivalence of these devices with PFDs and soil adsorption basins. Figure 7 compares the performance of the devices. Figure 8 shows only the part of the rain garden record that does not meet either the PFD or soil adsorption basin criterion.

Of the 525 bypass events experienced, approximately 25% of overflows (128 events) occur at an intensity less than 5 mm/hr or with an event depth less than 25 mm. This is 3% of the record events. That means that a rain garden does not always treat an event that could be treated by a PFD or soil adsorption basin. However, these events equate to less than 1% of the total volume. What this shows is that the bypass that occurs within these bounds is relatively minor compared to the total record.

Figure 7: Rain Garden Performance Compared with PFD and Soil Adsorption Basin Treatment Criteria

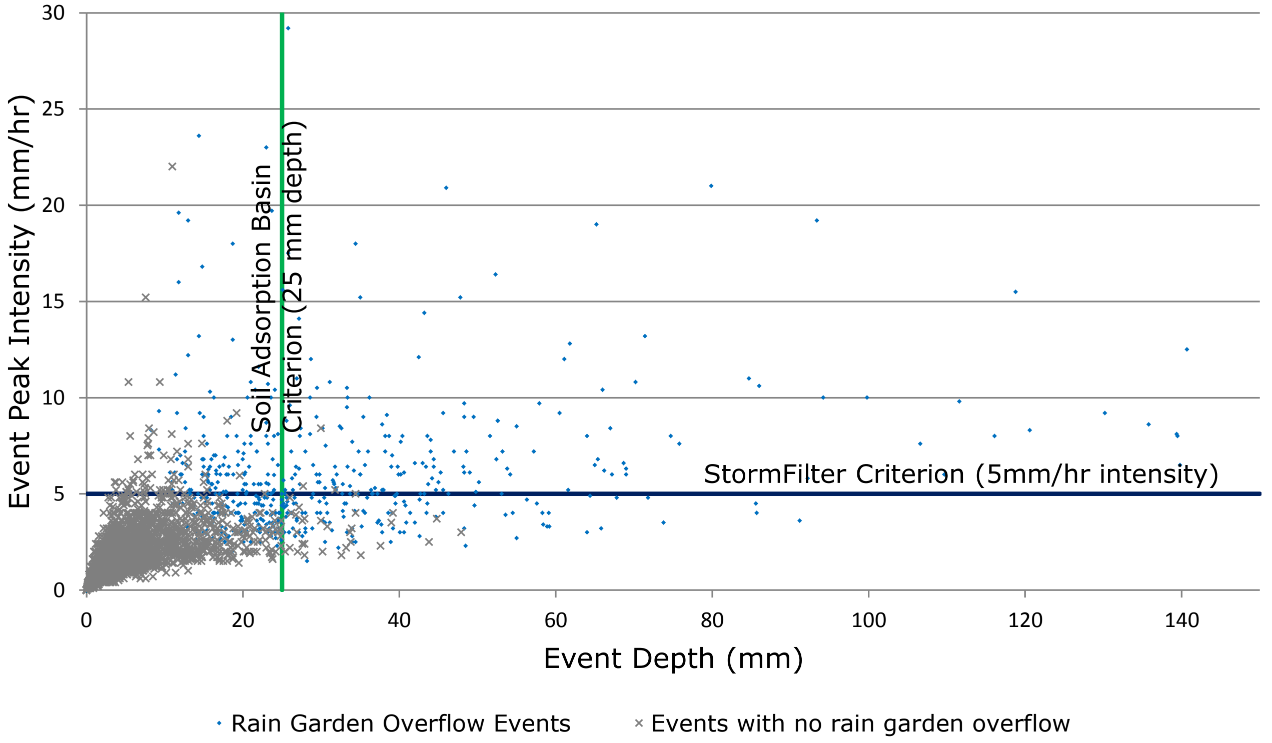
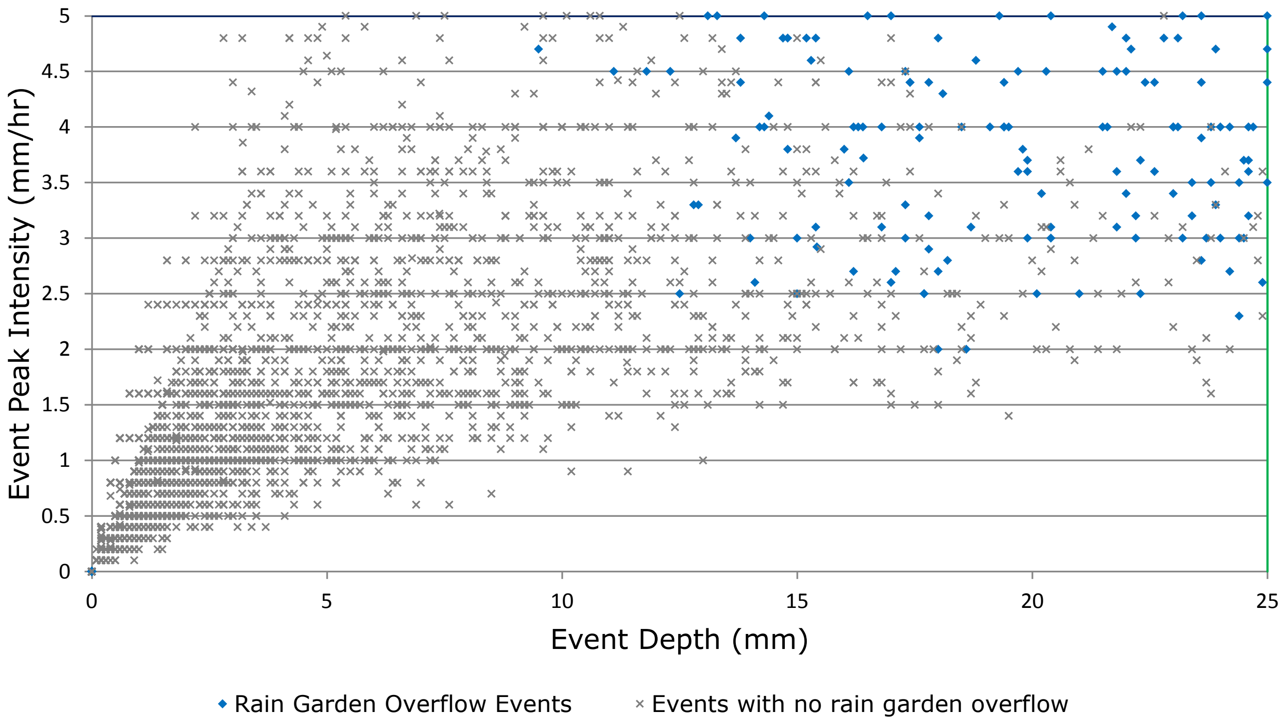


Figure 8: Rain Garden Performance Compared with PFD and Soil Adsorption Basin Treatment Criteria – Events Not Meeting Design Criteria Only

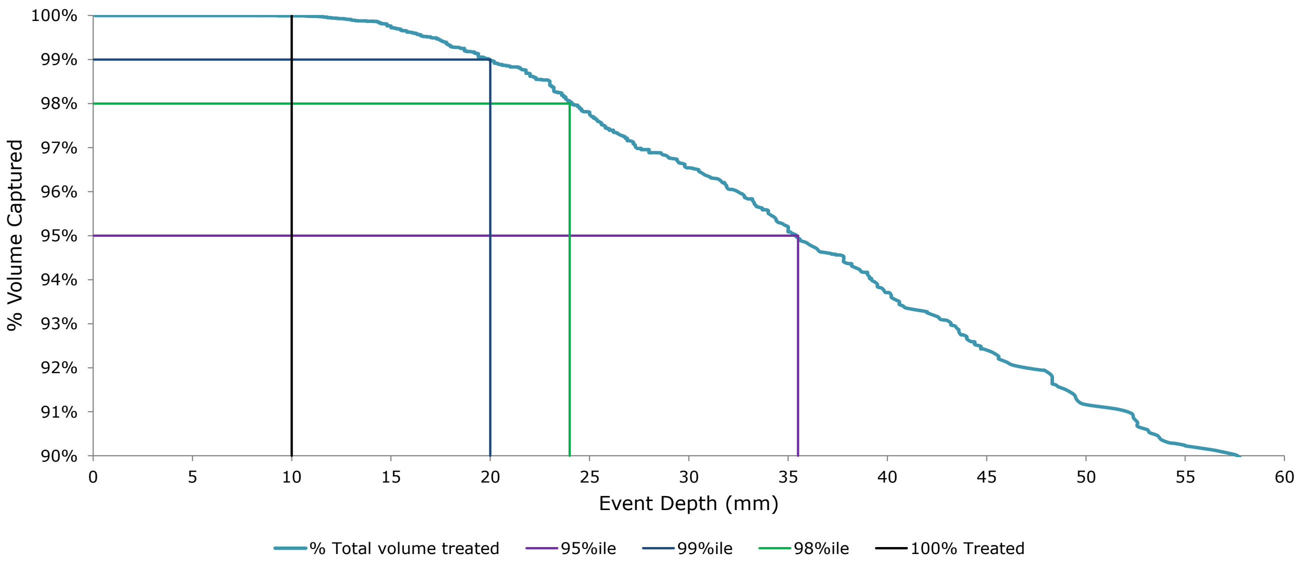


An alternative way to analyse the data is to plot (using the long term record) the percent of total volume treated versus event depth (Figure 9). This shows that when designed using the parameters outlined in this paper a rain garden will treat:

- 98% of the long-term average runoff volume for rainfall events less than 24 mm

- 99% of the long-term average runoff volume for rainfall events less than 20 mm
- 100% of the long-term average runoff volume for rainfall events less than 10 mm.

Figure 9: Percent Total Volume Treated vs Event Depth



Overall it was considered that sufficiently close hydrologic treatment equivalence was demonstrated for bioretention devices.

Although close hydrologic treatment equivalence was demonstrated, each device has different capability when it comes to specific contaminant removal. Therefore it remains for the stormwater designer to still assess which device is appropriate for each situation.

5 CONCLUSIONS

This study examined the key design variables for three stormwater treatment devices suitable for retrofitting in the Avon River catchment. The aim was to determine the optimum configuration for Christchurch conditions and to establish equivalence with other stormwater treatment devices used in Christchurch. Capture and treatment of 80% of the long term rainfall series runoff volume was chosen as the criteria for the assessment of the hydrologic treatment performance of these devices.

The methodology developed enabled bioretention and proprietary filtration devices to be sized using the local long term 30 minute rainfall series. Using this, close hydrologic equivalence between devices was demonstrated giving designers greater certainty in the selection of devices.

For proprietary filtration devices, a design rainfall intensity of 5 mm/hr was selected to ensure capture of at least 80% of the runoff volume. Bioretention devices are more complicated, but for rain gardens an extended detention depth of 300 mm, a design infiltration rate of 20 mm/hr and a filter media depth of 600 mm will enable capture (and therefore treatment) of at least 80% of the runoff volume. For stormwater tree pits the infiltration rate used was the same, but were assessed using an extended detention depth of 150 mm and a filter media depth of 1000 mm. A 3.5 m by 3.5 m stormwater tree pit can treat an area of 350 m^2.

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