Christchurch Stormwater Tree Pit Design Criteria: Detailed Report

Assets and Network Unit

Christchurch City Council

15 October 2014

Report Approvals Panel		
Prepared by	Mark Stone Aurecon New Zealand Ltd	15/10/2014 Date
Reviewed by	Peter Christensen Aurecon New Zealand Ltd	15/10/2014 Date
	Ken Couling Capital Assets Delivery	15/10/2014 Date
Approved for release by	Fiona McKay Team Leader Capital Investigations	15/10/2014 Date

Christchurch City Council

Document Control Record

Document Control					
Rev	**Date**	**Revision details/status**	**Author**	**Reviewer**	**Approver**
1	14 Feb 2014	Preliminary issue	MS	PC / KC	FM
2	15 Oct 2014	Updated issue	MS	PC / KC	FM
Current revision		**2**			

TRIM References:

Word version: 14/1232613

PDF version: 14/215638

Executive Summary[1]

Introduction

The Avon Stormwater Management Plan (SMP) will recommend that stormwater tree pits be used as one of the treatment tools, particularly in the central city where widespread tree planting is proposed as part of the city rebuild. 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. Significant non-stormwater benefits are also provided.

This study develops Christchurch specific stormwater tree pit design criteria by:

- Analysing the historic rainfall record to determine hydrologic and treatment design parameters (to achieve 80% annual runoff volume capture).
- Investigating the most suitable stormwater tree pit design and street layouts in consultation with the City Arborist.
- Determining what constraints restrict stormwater tree pit use.
- Quantifying the stormwater treatment provided by stormwater tree pits.
- Considering any potential negative impacts on existing infrastructure.
- Estimating capital and operational costs.

The study found that the optimal stormwater tree pit dimensions have a 3.5 x 3.5 x 1.5m soil volume and 3.5 x 2.3 x 0.15m ponding volume. When spaced at 20m (proposed city street tree spacing) stormwater tree pits will capture 92% of stormwater runoff volume (road catchment only). Increasing the spacing to 35m achieves the goal of 80% capture of stormwater runoff volume. The soil volume and ponding volume footprint dimensions will however be influenced by constraints such as underground services and therefore will vary for different locations. Recommended stormwater tree pit design parameters to achieve this treatment are presented in the body of the report.

A selection of stormwater tree pit layouts are presented in this report which includes treatment devices located behind the kerb alignment and within the on-street parking bay.

[1] The results of the study are presented in two reports. This report is a detailed report which provides the background to the conclusions presented in the summary report, as well as more information on design details and considerations. There is a companion summary report to present the main conclusions and recommendations reached in this study.

A preliminary cost estimate for construction of stormwater tree pits in the city is $9,400 ex GST, with the incremental cost over conventional tree pits estimated as $1,800 ex GST.

Central Christchurch Public Realm Network Plan

The Central Christchurch Public Realm Network Plan (PRNP) provides a unified and comprehensive reference document for the design and delivery of public realm improvement projects in the central city.

The Central Christchurch Public Realm Network Plan contains design criteria to introduce street tree planting in all new streetscape projects and promote integrated surface stormwater treatment into the design of the public realm.

> ***"Promote integrated surface stormwater treatment into the design of the public realm."***
> ***Central Christchurch Public Realm Network Plan, 2014.***

Christchurch City Council Stormwater Tree Pit Strategy

The Christchurch City Council (CCC) stormwater tree pit strategy is presented below. This strategy must be considered for the design of all new streetscape projects in Central Christchurch.

- Stormwater tree pits are the preferred treatment method in the Central City because they are consistent with the street landscape strategy in the Central Christchurch Public Realm Network Plan.

- Rain gardens are generally preferred elsewhere within the city however stormwater tree pits and can be used where appropriate.

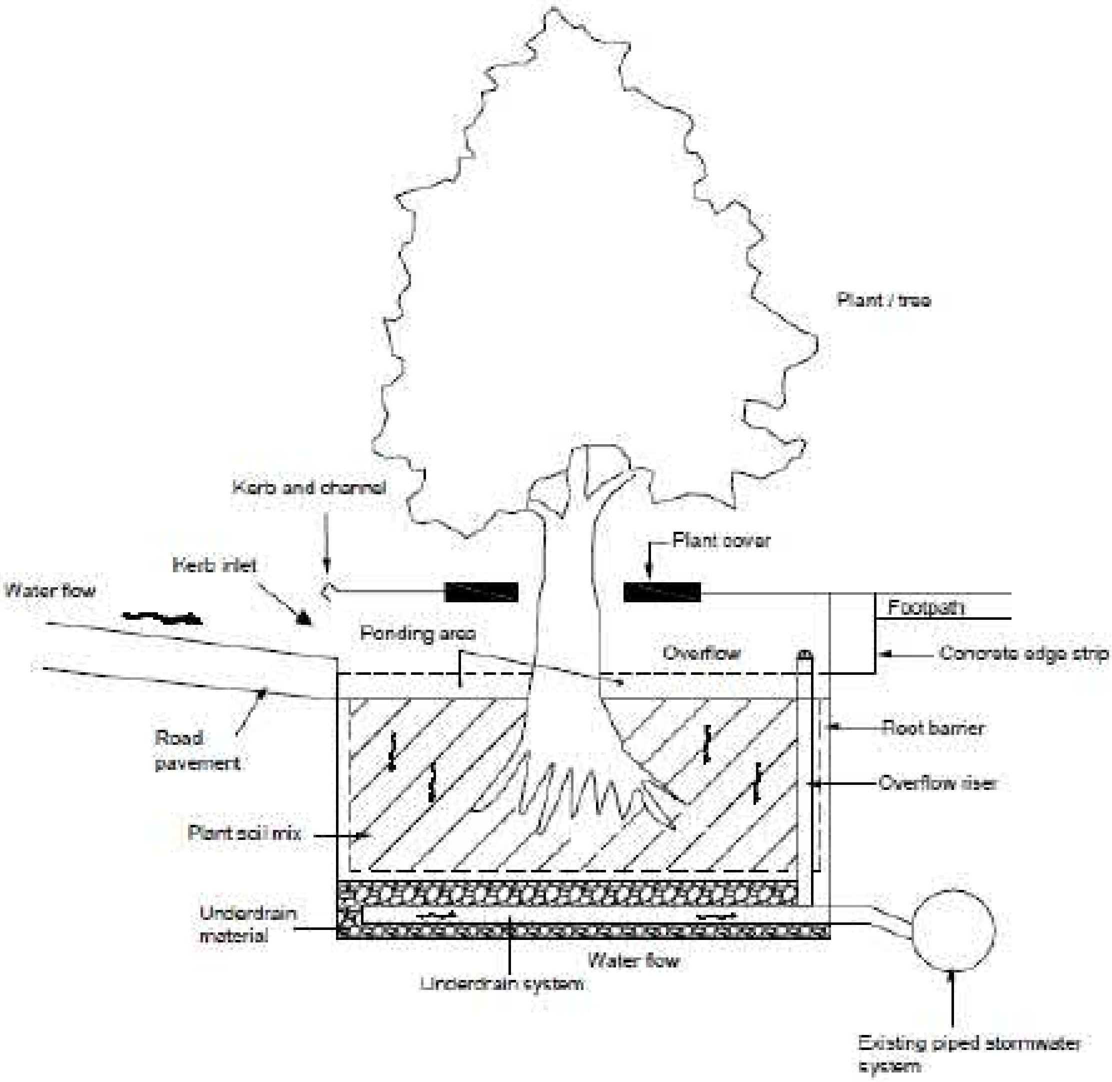
- Constraints such as underground services may restrict the use of stormwater tree pits within the Central City. Stormwater treatment solutions that combine stormwater tree pits and rain gardens can be considered.

- Include passive irrigation of conventional tree pits within the Central City in locations between stormwater tree pits and where stormwater tree pits are not viable. This will ensure all street trees encounter similar growing conditions, significantly improve tree health and the passive irrigation tree pits will reduce the sediment load entering either stormwater tree pits or rain gardens located further downstream.

- Use a combination of stormwater treatment devices within the stormwater treatment strategy for all new streetscape projects in Christchurch where possible.

- Ensure the design of all stormwater tree pits and rain gardens carefully consider maintenance and operational considerations to the satisfaction of CCC.

A schematic of typical stormwater tree pit components is presented below.



Source: Operation and Maintenance of Stormwater treatment devices in the Auckland Region (Auckland Council, 2010).

Summary of Design Parameters

The recommended stormwater tree pit design parameters which achieve greater than 80% stormwater runoff volume capture are listed below:

EDD recommendation (Section 4.4.1) Adopt an extended detention depth (EDD) of 150mm for stormwater tree pits in the CBD. In areas constrained by shallow stormwater pipes, the EDD can be reduced to a minimum depth of 100mm. A larger EDD of 300mm could be considered in areas outside the CBD area which have larger contributing catchments and where the selected tree species is not affected by a deeper EDD. Note that adopting an EDD greater than 150mm will significantly reduce the number of tree species that can be used in the stormwater tree pit.
Stormwater tree pit spacing recommendation (Section 4.4.2) Street tree planting shall be determined by the City Arborist who has specified a preference that trees be planted at 15-20m spacing on both sides of the street (either alternate or opposite). Stormwater tree pits shall be spaced at a maximum 35m spacing (optimum layout) to ensure the stormwater treatment objectives are achieved for the CBD area. Note that this spacing assumes stormwater tree pits capture road reserve catchment runoff only. In areas where stormwater tree pits cannot be placed at 35m maximum spacing due to infrastructure constraints, a larger stormwater tree pit or combined stormwater tree pit and rain garden should be located at the downstream end of the block where possible.
Stormwater tree pit dimension recommendation (Section 4.4.3) Stormwater tree pits shall be 3.5 x 3.5m in size (optimum layout) with a minimum planting depth of 1.5m in accordance with recommendations from the City Arborist. The 1.5m depth should include the filter media, transition layer and submerged zone (if required). In areas where a 3.5 x 3.5m tree pit cannot be adopted due to infrastructure constraints such as existing buried services, a rectangular tree pit can be adopted that maintains the same soil volume. A minimum tree pit width of 2m should be adopted and where possible on-street parking bays should be widened to 2.5m to allow a wider tree pit to be adopted. The open area for ponding of EDD shall preferably be 3.5m (long) by 2.3m (wide). Additional stormwater tree pit width could be provided (where possible) surrounding the base stormwater tree pit footprint to provide additional room for roots to spread laterally to anchor the tree. This is particularly important in areas where the selected stormwater tree pit footprint is smaller than preferred.

Infiltration Rate recommendation (Section 4.4.4)

Adopt a minimum initial infiltration rate of 50mm/hr and maximum of 150mm/hr for infiltration media for Avon SMP stormwater tree pit, with an infiltration rate of 30mm/hr used for design purposes.

It is recommended that Resource Consent conditions should specify a *minimum initial* infiltration rate of 50mm/hr and an operational infiltration rate between 50 and 150mm/hr.

Rejuvenation of the media must take place when the infiltration rate falls below 20mm/hr. Rejuvenation of media will typically comprise replacing the upper 100mm of filter media soil.

These are the same infiltration rates adopted for rain gardens in Christchurch.

Media depth recommendation (Section 4.4.5)

Adopt a filter media depth of 1.5m. This depth should include the filter media, transition layer and submerged zone (if required).

The minimum filter media depth (excluding the transition layer and submerged zone) shall be 1.0m to ensure tree health is not adversely affected. If this minimum depth cannot be achieved (as will be the case in areas with shallow stormwater pipes) then the use of combined stormwater tree pits and rain gardens or rain gardens only should be considered instead of a stormwater tree pit. The rain garden filter media depth shall ideally be 600mm but 300mm minimum.

Alternatively it may be possible to reduce the filter media depth and select tree species that can withstand roots being saturated for long periods however; provision to prevent roots entering the underdrain and outlet pipe is required.

The transition layer depth shall be a minimum of 100mm.

The drainage layer depth will be determined by the underdrain pipe diameter, minimum pipe cover (50mm minimum) and depth of gravel beneath underdrain (optional to aid infiltration of stormwater into in-situ soil). A 150mm minimum drainage layer depth is recommended for stormwater tree pits with a 100mm diameter underdrain pipe. The base of the drainage layer should be flat.

Media Mix recommendation (Section 4.4.6)

<u>Plant Soil</u>

Follow NZTA (2010) or FAWB (2009) guidelines. Ideally the proportion of silt and clay fines will be less than 3% by weight.

If a proportion of silt and clay fines greater than 3% by weight is required; then infiltration testing of the filter media soil should be undertaken to assess the suitability of the soil for use in the stormwater tree pit.

The proportion of organic matter can be 10 – 30% as per the Auckland Council draft rain garden guidelines.

Transition Layer, Drainage Layer & Submerged Zone Material

Follow NZTA (2010) or FAWB (2009) guidelines.

Structural Soil

Use structural soil composition as specified by the City of Melbourne, with adjustments for locally available products as necessary. The proportion if fines must be carefully specified to ensure that the 50mm/hr minimum infiltration rate can be achieved. Infiltration testing of structural soil media should be undertaken prior to installation.

Mulch

The surface of the stormwater tree pit shall include a mulch layer to prevent weeds and help keep soil moist. A non-floatable gravel mulch shall be specified.

A biodegradable weed mat can be used to restrict weed growth until vegetation is fully established.

Recommended Separation to Median Groundwater Level (Section 4.4.8)

A minimum 0.5m separation to median groundwater level from the base of stormwater tree pit is recommended. Seasonal fluctuations in groundwater levels should be considered whilst designing stormwater tree pits. The *Assessment of Median Shallow Groundwater Surface for Christchurch and Surrounding Areas* (Tonkin & Taylor, 2012) report identifies a seasonal variability of 1m in the inland zone and 0.5m or less in the eastern/coastal zone.

The median groundwater depth and likely groundwater level fluctuations should be considered whilst selecting appropriate tree species for stormwater tree pits.

Consider the potential impacts of sea level rise on groundwater levels within Christchurch and the corresponding impact on separation to median groundwater levels. This report includes a map identifying areas within the City where stormwater tree pits may be unsuitable without careful design consideration.

Submerged Zone recommendation (Section 4.4.7)

Include a submerged zone in stormwater tree pits when the depth of existing stormwater infrastructure (required to receive treated stormwater flows) is shallower than the minimum stormwater tree pit depth or when a submerged zone is considered beneficial for tree health.

Determine whether a submerged zone is required before selecting a tree species. A submerged zone may restrict the tree species that can be planted in the stormwater tree pit.

A submerged zone can be included if the saturated zone created would provide additional benefit to the trees health during dry periods. Note that in this case an impermeable liner could be installed at the base of the stormwater tree pit to prevent stormwater infiltrating into the in-situ soil. Alternatively it may be beneficial to have a submerged zone and infiltration in areas with low in-situ infiltration rates, as is likely to occur in areas with poorly drained and imperfectly drained soil.

Submerged zones will be required in most areas within the city due to the shallow depth to existing stormwater infrastructure.

Recommended underdrain specifications (Section 4.4.9)

The underdrain (when required) shall comprise a slotted PVC (typically 100mm diameter) pipe constructed in a 150mm minimum thick gravel drainage layer beneath the stormwater tree pit. Slotted PVC pipes are preferable to flexible perforated pipe. The underdrain shall be installed at constant zero grade within the drainage layer.

A non-slotted direct connection shall be made to existing stormwater pipes adjacent the stormwater tree pits. Alternatively the underdrain can discharge to a soak pit.

A standpipe (flushing point) should typically be provided to facilitate underdrain inspection and maintenance.

An underdrain collection pipe is not strictly necessary in a stormwater tree pit with a submerged zone as inclusion of an upturn elbow (riser) outlet confines exit flow to be via this path and the drainage layer can act as a surrogate collection pipe. The riser outlet should extend to the surface of the stormwater tree pit to allow inspection and maintenance.

An underdrain may potentially be omitted from the stormwater tree pit in areas with moderately well drained and well-drained soil as identified on the Landcare soil maps. Infiltration testing should be undertaken to ensure that the in-situ infiltration rate (with a factor of safety of 3 applied as per the CCC WWDG) exceeds the design infiltration rate of the filter media.

Tree root barrier recommendation (Section 4.4.10)

Tree root barriers shall be provided for stormwater tree pits when the minimum offset between utility services cannot be achieved. Root barriers will typically only be required along the pavement and footpath edges of the stormwater tree pit.

Tree root barriers shall be constructed in accordance with the Council Construction Standard Specification (CSS) requirements. The tree root barriers shall extend from the base of the stormwater tree pit to the surface elevation. Geofabric is not required on stormwater tree pit edges where root barriers are installed.

Stormwater tree pit surface finishing recommendation (Section 4.4.11)

The surface finishing of stormwater tree pits should either comprise an uncovered open area (with rain garden planting) or a tree grate covering the entire open ponding area.

Stormwater tree pits with an open surface (i.e. no tree cover) should consider the use of raised wheel stops on all edges adjacent the footpath for pedestrian safety.

The stormwater tree pit surface should be covered with a non-floatable gravel mulch.

If a weed mat is used it should be biodegradable.

Tree species selection recommendation (Section 4.4.12)

Use tree species as identified by the City Arborist. Tree species must be able to tolerate conditions that may negatively impact plant growth. For example, plants in bioretention systems may be exposed to alternating cycles of wet and dry conditions, ponding and loading of fine sediments. Filter media is typically sandy and will dry out relatively quickly.

Tree species must be able to tolerate the removal and replacement of the upper 100mm of filter media as this may be required to reinstate the infiltration capacity of the filter media.

Tree species should be determined by biodiversity considerations, site conditions (e.g. median groundwater level, presence of submerged zone), design objectives (e.g. stormwater treatment, habitat creation), and the surrounding landscape (e.g. aesthetic conditions, shade).

Drawdown Time recommendation (Section 4.4.13)

Adopt a design drawdown time of one day (24 hours) for stormwater tree pits within the CBD.

Vegetation specification recommendation (Section 4.4.14)

Use plant species as identified by a landscape architect based on biodiversity considerations, site conditions, design objectives, stormwater treatment, and landscape considerations.

Plant species must be able to tolerate conditions that may negatively impact plant growth. For example, plants in bioretention systems may be exposed to alternating cycles of wet and dry conditions, frost, ponding and loading of fine sediments. Filter media is typically sandy and will dry out relatively quickly.

The planting density should be high (at least 10 plants/m^2 for sedges and rushes) to increase root density, protect surface porosity, promote even distribution of flows, increase evapotranspiration loses (which helps reduce runoff volume and frequency), and reduce the potential for weed invasion. Shrubs should be planted at a density of <1 plant/m^2 and according to landscape requirements.

Liner recommendation (Section 4.4.15)

A heavy duty flexible membrane, such as high-density polyethylene (HDPE), can be used to line the base of the drainage layer and sides of the stormwater tree pit to above the submerged zone water level. This liner will prevent the submerged zone from draining (improving plant health during dry periods) but will also prevent recharge of groundwater and may potentially worsen liquefaction from the creation of saturated soil conditions by the submerged zone. However, the use of a liner is generally not recommended in Christchurch.

If a submerged zone is not required for the tree species selected then a liner should be omitted to allow recharge of groundwater. However, the base and sides of stormwater tree pits could be lined in areas at risk of liquefaction.

Stormwater tree pits without a submerged zone but in areas at risk of liquefaction could be lined with a geofabric to allow recharge of groundwater but to prevent liquefaction entering the stormwater tree pits.

When stormwater tree pits are constructed adjacent to existing services a root barrier should be included to prevent damage to services. In these areas the root barrier can be used instead of the geofabric liner.

Overland Flow Path Capacity recommendation (Section 4.4.16)

A key design consideration is ensuring that overland flow paths on roads have adequate capacity to convey and/or store flows beneath the finished floor level of adjacent developments during the 2% AEP event.

Designers must ensure that the pipe and kerb can convey the 20% AEP event beneath the top of kerb level and that the static 2% AEP event water level is not above adjacent finished floor levels, ideally with freeboard included.

Stormwater Tree Pit Stormwater Inlet and Flow Bypass (Section 4.4.16)

Stormwater tree pits can be incorporated into the kerb layout in numerous configurations. Some configurations that are likely to occur in the Christchurch CBD include:

- Stormwater tree pit constructed behind the kerb alignment: Stormwater runoff can enter the stormwater tree pit via a kerb opening and larger flows can bypass the device.
- Stormwater tree pit constructed in the on-street parking bay and on-street parking bay pavement regraded away from the footpath back to a concrete channel: Stormwater runoff can enter the stormwater tree pit via a kerb opening and larger flows can bypass the device within the concrete channel. This configuration requires careful detailing to prevent worsening flood impacts in traffic lanes and the on-street parking bay.

- Stormwater tree pit constructed in the on-street parking bay and kerb and channel graded around the stormwater tree pit build-out.
- Stormwater tree pit constructed in the on-street parking bay and on-street parking bay grading to remain unchanged: Stormwater runoff can enter the stormwater tree pit via a kerb opening on the upstream edge and larger flows can pass through the stormwater tree pit via a kerb opening on the downstream face. This configuration would result in the stormwater tree pit being constructed in the existing overland flow path along the kerb. Therefore overland flow during larger storm events, such as the 2% AEP event, would need to pass through and around the stormwater tree pit. This configuration therefore requires careful detailing to prevent worsening flood impacts in traffic lanes, the on-street parking bay and adjacent properties.

The dimensions of kerb openings should be sized to prevent flooding of adjacent properties, minimise inundation extents and prevent mulch and filter media from being damaged.

Stormwater Kerb Outlet recommendation (Section 4.4.16)

All new stormwater laterals discharging clean roof or other treated stormwater should be provided with a direct connection to the existing CCC piped stormwater network. This provides a significant stormwater treatment outcome as it reduces the footprint of treatment devices in the street and ensures that these devices only treat the most polluted water.

Stormwater kerb outlets from existing developments should be replaced with direct connection stormwater laterals to the CCC piped stormwater network and on-site treatment provided where possible.

Sediment Load Management recommendation (Section 4.4.17)

A key consideration for the design of stormwater tree pits and rain gardens in post-earthquake Christchurch is construction sediment loads. All new streetscape projects with stormwater tree pits and rain gardens included must consider construction stage sediment loads, future construction sediment loads from redevelopment sites adjacent the road corridor and facilitate a strategy to ensure the performance of stormwater treatment devices is not jeopardised.

Some potential design considerations include:

- Include a small sediment forebay within all stormwater tree pits and rain gardens. This could be either permanent or temporary until the completion of adjacent construction sites.
- Careful monitoring during construction of the streetscape project by the superintendent and ECan.
- When stormwater tree pits and rain gardens are combined, locate the kerb inlet away

from stormwater tree pit.

- Appropriate construction staging. The filter media for stormwater tree pits and rain gardens should not be installed until the road pavement and footpath has been established. A comprehensive erosion and sediment control plan must be developed.

Design Flow Chart

Two of the key constraints identified that influence the design of stormwater tree pits in the city are the depth to median groundwater level and depth to existing stormwater pipe invert level. These two constraints influence the design of stormwater tree pits and may also result in them not being viable for use in certain areas.

The following figure presents a flow chart that can be used to assist with the consideration of median depth to groundwater and depth to stormwater pipe invert level constraints for stormwater tree pits. This flow chart should be used in conjunction with the stormwater tree pit arrangements in Section 4.2.

TREE PIT DESIGN FLOW CHART

For consideration of median depth to ground water and depth to stormwater pipe invert level (IL) constraints

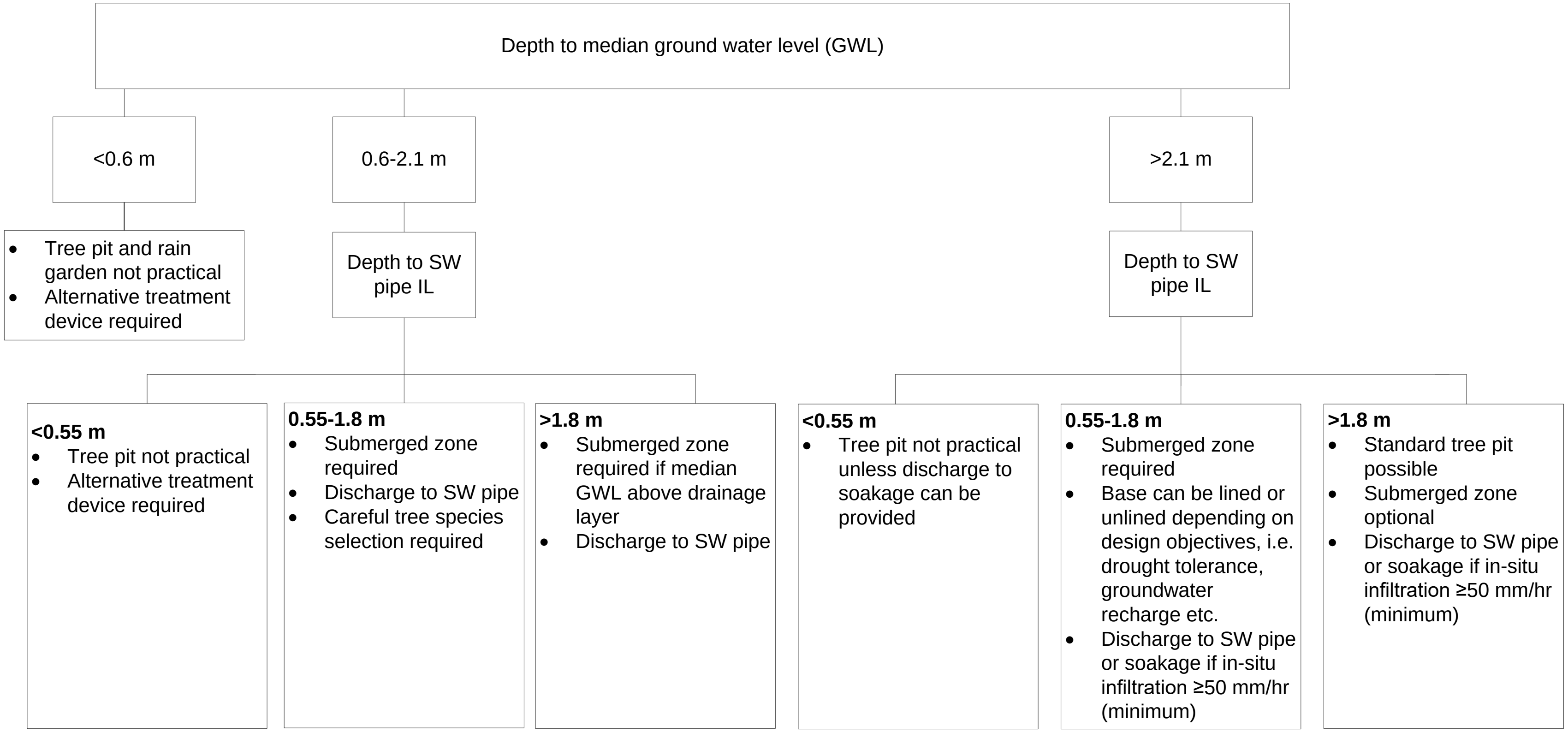


TABLE OF CONTENTS

1 INTRODUCTION 18

1.1 Background 18

1.2 Study aims 19

1.3 Methodology 19

1.4 Terminology 20

1.5 Proposed CBD Streetscape Opportunities 20

2 THE BENEFITS OF TREES IN THE CITY 26

3 INCORPORATING STREET TREES INTO THE STORMWATER STRATEGY 27

4 TREE PIT DESIGN CRITERIA 28

4.1 Stormwater Tree Pit design formula 28

4.2 Stormwater Tree Pit configuration 29

4.3 Stormwater tree pit pollutant removal efficiency 39

4.4 Design Parameters 41

4.4.1 EDD Recommendation 41
4.4.2 Stormwater tree pit spacing 43
4.4.3 Stormwater tree pit dimensions 43
4.4.4 Media Infiltration rate 45
4.4.5 Media Depth 46
4.4.6 Filter Media 47
4.4.7 Submerged Zone 56
4.4.8 Separation to median groundwater level 59
4.4.9 Underdrain 62
4.4.10 Root barriers 63
4.4.11 Tree grates 64
4.4.12 Tree Species Selection 66
4.4.13 Drawdown Time 69
4.4.14 Vegetation Specification 70
4.4.15 Liner Specification 71
4.4.16 Stormwater Tree Pit Stormwater Inlet and Flow Bypass 72
4.4.17 Sediment Load Management 75

5 LEVEL OF STORMWATER TREATMENT PROVIDED 77

5.1 80% Capture of Stormwater Volume 77

5.1.1 Road and footpath only catchment 78
5.1.2 Road, footpath and adjacent lot catchment 78
5.1.3 Catchment area to achieve 80% capture of stormwater 78

5.2 Reduction in annual pollutant load 79

5.2.1 MUSIC Model 79
5.2.2 Estimated Reduction in Mean Annual Loads 80

6 POTENTIAL INFRASTRUCTURE IMPACTS 83

7 PROPRIETARY PRODUCTS 84

8 MAINTENANCE REQUIREMENTS 85

8.1 Tree maintenance 85

8.2 Generic Bioretention Device Maintenance Requirements 85

8.3 Underdrain Considerations....90
8.4 Maintaining Porosity of Filter Media....91
8.5 Rejuvenation of Filter Media....91

9 COST ESTIMATES....93
9.1 Capital Cost....93
9.2 Annual Cost Requirements....94

10 CONCLUSIONS....95

11 ACKNOWLEDGEMENTS....95

12 REFERENCES....96

APPENDIX A....98

Index of Figures

FIGURE 1 CENTRAL CITY ROAD USE HIERARCHY PLAN (SOURCE: CHRISTCHURCH CENTRAL RECOVERY PLAN). 21
FIGURE 2 TYPICAL "WALKING" PRIORITISED CROSS SECTION (SOURCE: CHRISTCHURCH CENTRAL RECOVERY PLAN). 22
FIGURE 3 TYPICAL "CYCLING" PRIORITISED CROSS SECTION (SOURCE: CHRISTCHURCH CENTRAL RECOVERY PLAN). 23
FIGURE 4 TYPICAL "MAIN STREET" PRIORITISED CROSS SECTION (SOURCE: CHRISTCHURCH CENTRAL RECOVERY PLAN). 24
FIGURE 5 TYPICAL "CAR TRAVEL" PRIORITISED CROSS SECTION (SOURCE: CHRISTCHURCH CENTRAL RECOVERY PLAN). 24
FIGURE 6 TYPICAL "PUBLIC TRANSPORT" PRIORITISED CROSS SECTION (SOURCE: CHRISTCHURCH CENTRAL RECOVERY PLAN). 25
FIGURE 7 STORMWATER TREE PIT BEHIND KERB ALIGNMENT 30
FIGURE 8 STORMWATER TREE PIT IN ON-STREET PARKING BAY BUILD-OUT 31
FIGURE 9 COMBINED STORMWATER TREE PIT AND RAIN GARDEN BEHIND KERB ALIGNMENT 32
FIGURE 10 COMBINED STORMWATER TREE PIT AND RAIN GARDEN IN ON-STREET PARKING BAY BUILD-OUT 33
FIGURE 11 STORMWATER TREE PIT IN ON-STREET PARKING BAY GRADED TO KERB 34
FIGURE 12 STORMWATER TREE PIT (OR RAIN GARDEN) IN ISOLATED TRAFFIC ISLAND 35
FIGURE 13 PASSIVE IRRIGATION TREE PIT IN ON-STREET PARKING BAY GRADED TO KERB 36
FIGURE 14 PASSIVE IRRIGATION TREE PIT IN ON-STREET PARKING BAY GRADED AWAY FROM KERB 37
FIGURE 15 STORMWATER TREE PIT TYPICAL DETAILS 38
FIGURE 16 DRAINAGE LAYER BASE PROFILE 51
FIGURE 17 TYPICAL STRUCTURAL CELL CONFIGURATIONS 53
FIGURE 18 CHRISTCHURCH SOIL DRAINAGE (SOURCE: LANDCARE RESEARCH) 58
FIGURE 19 SUBMERGED ZONE SCHEMATIC AND INSTALLATION PHOTO (BROWN ET AL, 2009) 59
FIGURE 20 MEDIAN DEPTH TO GROUNDWATER WITHIN THE CBD 60
FIGURE 21 STORMWATER TREE PIT SUITABILITY BASED ON PREDICTED SEA LEVEL RISE IMPACTS 61
FIGURE 22 TYPICAL STORMWATER TREE PITS AND TREE GRATES 65
FIGURE 23 STORMWATER TREE PIT LAYOUT AT 35M MAX SPACING (OPPOSITE) 79
FIGURE 24 STORMWATER TREE PIT LAYOUT AT 35M MAX SPACING (ALTERNATE) 79
FIGURE 25 EXAMPLE OF BIORETENTION ISSUES REQUIRING MAINTENANCE 86
FIGURE 26 STORMWATER STORAGE BENEATH CLUSTERED TREE PIT TYPICAL CONFIGURATION 92

Index of Tables

TABLE 1 COMPOSITION RANGE OF FILTER MEDIA (NZTA, 2010) 49
TABLE 2 TYPICAL STRUCTURAL SOIL COMPOSITION 54
TABLE 3 SUITABLE TREE SPECIES (SOURCE: CCC) 67
TABLE 4 ESTIMATED REDUCTION IN MEAN ANNUAL LOADS FOR ROAD RESERVE CATCHMENT (20M STORMWATER TREE PIT SPACING) 81
TABLE 5 ESTIMATED REDUCTION IN MEAN ANNUAL LOADS FOR ROAD RESERVE AND LOT CATCHMENT (20M STORMWATER TREE PIT SPACING) 81
TABLE 6 ESTIMATED REDUCTION IN MEAN ANNUAL LOADS FOR ROAD RESERVE CATCHMENT (35M STORMWATER TREE PIT SPACING) 82
TABLE 7 INSPECTION AND MAINTENANCE TASKS FOR BIORETENTION SYSTEMS (SOURCE: FAWB, 2009) 87
TABLE 8 AUCKLAND COUNCIL RAIN GARDEN OPERATION AND MAINTENANCE GUIDELINES 89
TABLE 9 CAPITAL COSTS 93
TABLE 10 OPEX COSTS 94

1 INTRODUCTION

1.1 BACKGROUND

The Avon Stormwater Management Plan (SMP) will include stormwater tree pits as one of the treatment options, particularly for the central city due to the proposed widespread tree planting associated with the city rebuild. While traditionally street trees have been isolated from the stormwater system, it is now considered better practice to integrate them. However, there is a need to develop design criteria for implementation, and this is the purpose of this report.

The Central Christchurch Public Realm Network Plan contains design criteria to introduce street tree planting in all new streetscape projects and promote integrated surface stormwater treatment into the design of the public realm.

University of Sydney

Waitangi Park, Wellington

When integrated with the stormwater system, stormwater tree pits become a versatile 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.

As well as stormwater management benefits, stormwater tree pits also provide significant improvement in amenity, habitat, tree health, groundwater recharge, heat island reduction, carbon footprint, connection to nature, land values etc. It can also reduce the need for ongoing irrigation of trees during dry periods, and may reduce infrastructure damage associated with tree roots searching for water.

Stormwater tree pits also suit retrofit as they are easy to adapt to a range of catchment sizes and engineering constraints. For the Christchurch CBD and greater Avon catchment, stormwater tree pits offer the opportunity to treat stormwater runoff from smaller street-scale sub-catchments closer to the source.

1.2 STUDY AIMS

The aims of this study were to:

- Determine Christchurch specific stormwater tree pit design parameters using the historic Botanic Gardens 30 minute rainfall record (1963-2013) as the assessment base.
- Investigate the most suitable stormwater tree pit design and street layout (primarily for the CBD area although applicable to suburban and commercial/industrial streets as well).
- Determine what constraints restrict stormwater tree pit use.
- Quantify the stormwater treatment provided by stormwater tree pits.
- Determine any potential negative impacts on existing infrastructure.
- Estimate capital and operational costs.

This study builds similar studies to develop rain garden design criteria in Christchurch by Peter Christensen (2013, TRIM 14/419249) and StormFilter design criteria in Christchurch by Tom Parsons (2013, TRIM 13/763554).

1.3 METHODOLOGY

The study methodology to determine the most efficient design was to:

- Liaise with the City Arborist to determine the most appropriate stormwater tree pit dimensions, tree spacing, suitable tree species etc. Long term tree health was considered a vital component in the design.
- Establish suitable stormwater tree pit design parameters based on review of international best practice, local requirements and that are also generally consistent with the Council *Waterways, Wetlands and Drainage Guide* (WWDG, 2003) parameters.
- Model the design parameters against the historic continuous Christchurch 30 minute rainfall record (1963-2013) to determine the level of stormwater treatment likely to be provided. Estimate contaminant load reduction for a range of pollutants using the MUSIC model.

- Determine the most suitable locations for trees pits in the CBD in conjunction with the recently released *An Accessible City – Christchurch Central Recovery Plan: Replacement transport chapter – October 2013* (CERA, 2013) (henceforth referred to as '*An Accessible City*').
- Determine potential engineering impacts and possible mitigation measures.
- Review the implications of conflicts with underground services and measures available to mitigate against these.
- Investigate the use of proprietary stormwater tree pit products that are currently available.
- Develop a cost model to assess the impact of different configurations.
- Report to interested parties within Council.

1.4 TERMINOLOGY

Note that the following definitions have been adopted for this report to assist in differentiating between the proposed (bioretention) stormwater tree pits and conventional tree pits.

Bioretention	Used to denote a vegetated stormwater treatment device with an engineered soil media for infiltration, such as rain gardens and stormwater tree pits.
Stormwater Tree Pit	Stormwater tree pit designed as a stormwater quality improvement device and utilising bioretention filter media (similar to a rain garden) to treat stormwater runoff
Conventional Tree Pit	Conventional tree pit that is not designed as a bioretention device to treat stormwater runoff
Passive Irrigation Tree Pit	A tree pit designed to capture stormwater runoff for irrigation of street trees.

1.5 PROPOSED CBD STREETSCAPE OPPORTUNITIES

The decision to include trees in the proposed CBD streetscape provides an opportunity to integrate them into the overall stormwater management strategy. Constructing stormwater tree pit infrastructure at the same time as street renewal/reconstruction works also minimises the costs to install them. Depending on the contributing catchment area, it may be possible to achieve capture of 80% of stormwater runoff volumes (which is the benchmark for stormwater treatment in Christchurch).

An Accessible City presents the proposed central city road use hierarchy plan. The use of stormwater tree pits is likely to be applicable in most areas where trees are planned to be included within the streetscape, with the biggest constraint likely to be underground infrastructure. This will often be able to be mitigated through careful selection of tree species, and by providing slight variations to the typical stormwater tree pit design arrangement. However, in some locations service clashes will preclude the use of stormwater tree pits.

Based on the typical road cross sections presented in *An Accessible City* stormwater tree pits could potentially be included in streets with proposed “walking”, “Main Street”, “public transport” and “car travel” prioritisation. The inclusion of stormwater tree pits in proposed “cycling” prioritised streets is more difficult, and will be influenced by whether street trees can be constructed within footpaths and whether a raised kerb is constructed to separate traffic lanes and cycle paths. Stormwater tree pits could be used for small street trees located within the footpath and when a rumble strip is used to separate vehicle and cycle lanes.

The central city road use hierarchy plan from the Christchurch Central Recovery Plan is presented in Figure 1. Typical cross sections for walking, cycling, main streets, public transport and car priority transport modes are presented and described below.

Figure 1 Central City Road Use Hierarchy Plan (Source: Christchurch Central Recovery Plan).

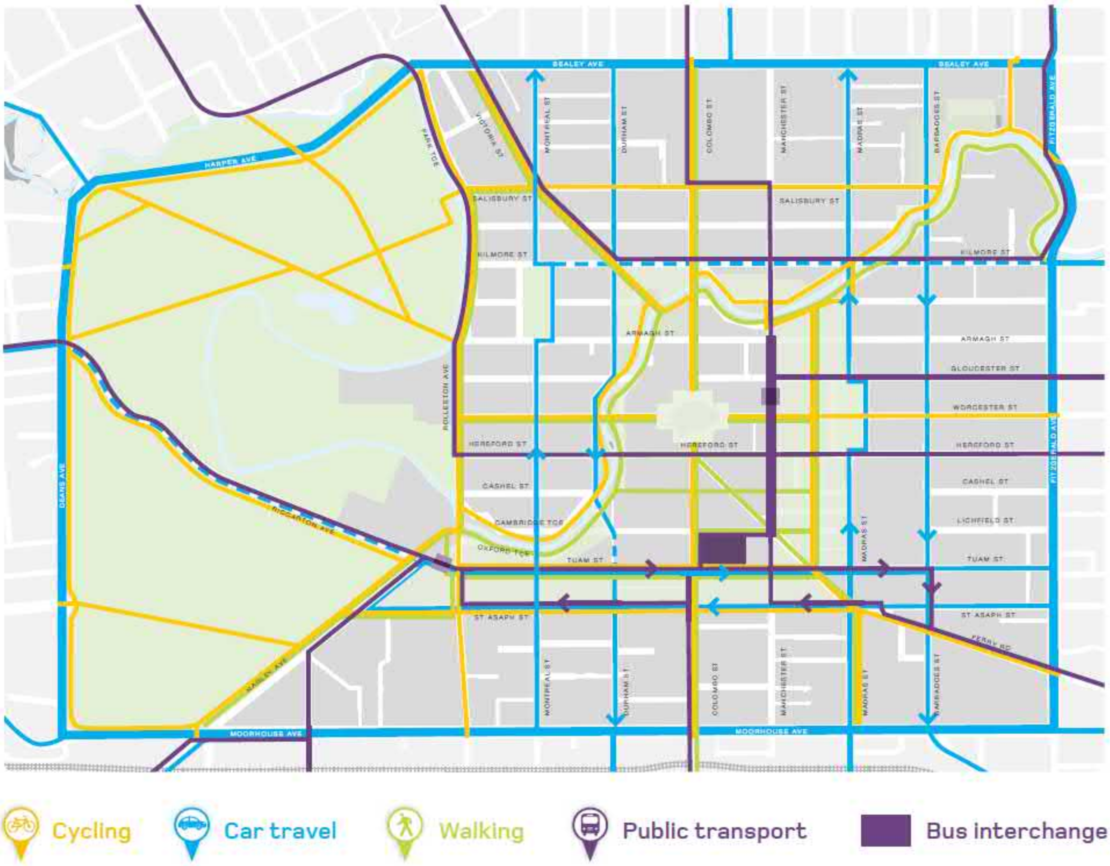


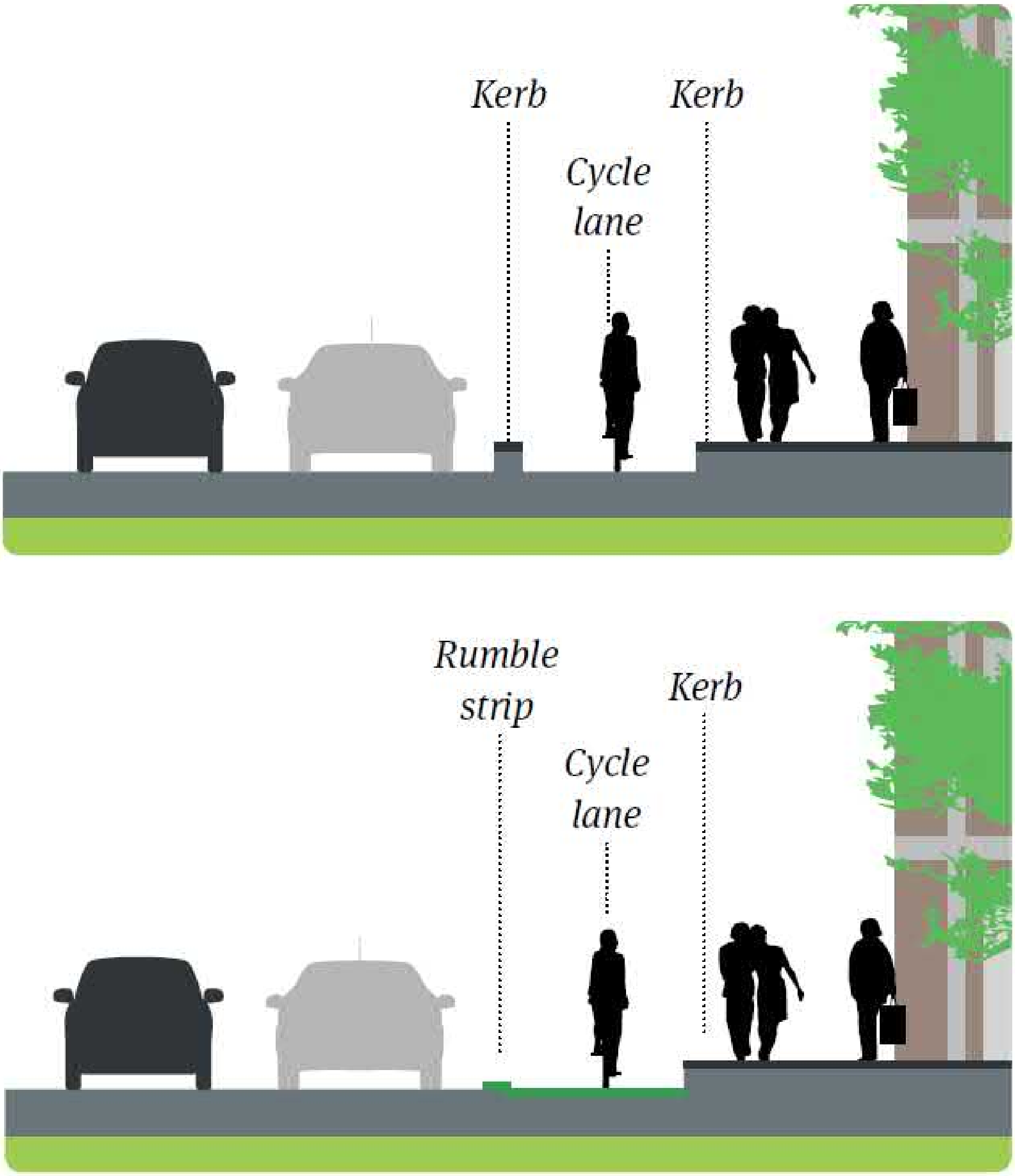
Diagram shows prioritised routes for different travel modes

Figure 2 Typical "Walking" Prioritised Cross Section (Source: Christchurch Central Recovery Plan).

Typical slow Core street – after

It can be seen from Figure 2 that "walking" prioritised streets are suitable for inclusion of stormwater tree pits within on-street parking bays as stormwater runoff can be easily captured by stormwater tree pits incorporated into this typical cross section layout.

Figure 3 **Typical "Cycling" Prioritised Cross Section (Source: Christchurch Central Recovery Plan).**



Possible cycle lane options

It can be seen from Figure 3 that "cycling" prioritised streets may not be suitable for the inclusion of stormwater tree pits because there may be no on-street parking bay incorporated to accommodate stormwater tree pits. It would however be possible to capture and divert stormwater runoff to stormwater tree pits located within the footpath if required.

Figure 4 Typical "Main Street" Prioritised Cross Section (Source: Christchurch Central Recovery Plan).

Typical Main Street

The Christchurch Central recovery plan identifies Victoria Street and Colombo Street will be developed as "Main Streets" due to their significant shopping and business use. It can be seen from Figure 4 that "Main Street" prioritised streets are suitable for inclusion of stormwater tree pits within on-street parking bays as stormwater runoff can be easily captured by stormwater tree pits incorporated into this typical cross section layout.

Figure 5 Typical "Car Travel" Prioritised Cross Section (Source: Christchurch Central Recovery Plan).

Indicative enhanced one-way distributor – Durham St / Cambridge Tce near the Ōtākaro/Avon River

It can be seen from Figure 5 that "Car Travel" prioritised streets are suitable for inclusion of stormwater tree pits within on-street parking bays as stormwater runoff can be easily captured by stormwater tree pits incorporated into this typical cross section layout.

Figure 6 Typical "Public Transport" Prioritised Cross Section (Source: Christchurch Central Recovery Plan).

Manchester St – indicative streetscape and bus lanes

Tuam Street – indicative streetscape and cycleway

It can be seen from Figure 6 that "Public Transport" prioritised streets are suitable for inclusion of stormwater tree pits within on-street parking bays or medians as stormwater runoff can be easily captured by stormwater tree pits incorporated into this typical cross section layout.

2 THE BENEFITS OF TREES IN THE CITY

Some of the services of establishing trees within the CBD and other areas around Christchurch are listed below.

- Visual services.
  - Provides amenity, sense of place and Garden City identity.
  - Aesthetic enhancement.
  - Place making.
  - Screen negative views.
- Environmental services.
  - Carbon storage and recycling nutrients.
  - Provides habitat and greater biodiversity.
  - Purification of air and reduces air pollution.
  - Connection to nature.
- Quality of life services.
  - Provides shade and cooling (reduction in heat island effects).
  - Reducing vehicle accidents by tree-lined streets calming traffic.
  - Provision of a microclimate – rain, sun, shade.
  - Improved physical health and mental well-being.
  - Reconnects the community with nature.
- Green infrastructure services.
  - Increased infiltration losses and groundwater recharge.
  - Increased canopy interception.
- Increased evapotranspiration losses.
  - Increased land value.
  - Extending the life of paved surfaces by cooling and removing excess ground water.
  - Tourism is supported by the Garden City image and trees promote enjoyment of the city.
  - More inviting streetscapes encourage customers to linger in retail and commercial areas.

- Additional stormwater management services.
    - Peak stormwater flow and volume reduction.
    - Reduction in pollutants entering receiving waterways
    - Ability to treat stormwater runoff from smaller street-scale sub-catchments closer to the source rather than end of line systems.

3 INCORPORATING STREET TREES INTO THE STORMWATER STRATEGY

The decision to include trees into the proposed CBD streetscape provides an opportunity to integrate them into the overall stormwater management strategy; providing stormwater quality, stormwater quantity and passive irrigation benefits.

Stormwater tree pits could form part of the overall strategy to treat stormwater runoff from the CBD area. Depending on the contributing catchment area, it may be possible to achieve capture of 80% of stormwater runoff volumes which is the benchmark for stormwater treatment in Christchurch.

Stormwater tree pit infrastructure can be constructed at the same time as street renewal / street reconstruction works. This helps to stage stormwater tree pit construction as well as minimising costs to install.

Providing stormwater tree pits at the location of all proposed street trees within the CBD will reduce the need for ongoing irrigation of trees during dry periods and may reduce infrastructure damage associated with tree roots searching for water.

The use of stormwater tree pits is likely to be applicable in most areas where trees are planned to be included within the CBD, though the biggest constraint is likely to be underground infrastructure and shallow groundwater levels. Consideration needs to be given to existing utility services protection and utility services relocations in the final design of a stormwater tree pit. It is considered that this will often be able to be adequately managed through careful selection of tree species and by providing slight variations to the typical stormwater tree pit design arrangement, though in some locations the services and/or depth to groundwater may preclude the use of stormwater tree pits.

4 TREE PIT DESIGN CRITERIA

Stormwater tree pits are similar to rain gardens in they are both bioretention devices used for stormwater treatment and therefore the mechanism of stormwater treatment for stormwater tree pits is the same as that for rain gardens. Stormwater tree pits can therefore be designed using the same design procedures as would be used for rain gardens.

Stormwater tree pits have a number of variables that dictate the design. A schematic of six stormwater tree pit layouts are presented in Figure 7 to Figure 12.

4.1 STORMWATER TREE PIT DESIGN FORMULA

Stormwater tree pits have two governing sizing requirements. The first is the minimum surface area and depth required to sustain a healthy tree. The minimum area recommended by the City Arborist is:

$$A_{TREE\ PIT} \geq 3.5\ m \times 3.5\ m \qquad \text{Equation (1)}$$

The second requirement is to size stormwater tree pits to capture 80% of the runoff volume, and this is based on design formulas and parameters developed for the *Rain Garden Design Criteria Report* (TRIM 14/419249). However, for stormwater tree pits it was decided to present a 'simplified' design approach due to the small footprint. As a result stormwater tree pits can be sized solely to provide the required extended detention (storage) volume calculated as follows:

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

Where:

A_{EDD} = Extended detention (storage) area of rain garden (m^2)

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

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

Note that Equation (2) is published in the New Zealand Transport Agency stormwater design guide, *Stormwater Treatment for Road Infrastructure*, (NZTA, 2010) Section 8.5.3.5.

It is noted that Equation (2) will size a stormwater tree pit to capture 80% of the stormwater runoff volume, when recommended design parameters are used. A first flush rainfall depth (d_{ff}) of 20mm will size a stormwater tree pit to capture 80% of stormwater runoff volume. However, in the CBD area, stormwater tree pit sizes will be set based on the required pit size to sustain healthy trees whilst avoiding infrastructure constraints such as existing utility services. In this study an assessment of the percentage of stormwater runoff captured for standardised stormwater tree pit dimensions has been undertaken, rather than sizing the device to capture 80% of the flow volume. This results in a percentage of stormwater runoff capture equal to, less than and greater than 80% based on the contributing catchment area, stormwater tree pit spacing and stormwater tree pit design parameters selected.

Where constraints do not exist then stormwater tree pits should be sized to be the greater of Equations (1) or (2).

4.2 STORMWATER TREE PIT CONFIGURATION

Stormwater tree pits are proposed to be located primarily within existing on-street car parking spaces in the Christchurch CBD, but also in median strips and verges for some street configurations. This ensures that vehicle, pedestrian, bike and public transport movement is not impacted and only a limited number of car parking spaces will be lost for street tree installation.

Some potential stormwater tree pit configurations are presented in Figure 7 to Figure 12. Figure 13 and Figure 14 present two passive irrigation tree pit details and Figure 15 presents typical details for stormwater tree pits.

Potential stormwater tree pit locations have been identified based on the road hierarchy plans and typical road sections presented in *An Accessible City* (refer figures in Section 1.5).

Based on the typical road cross sections presented in *An Accessible City* stormwater tree pits could potentially be included in streets with proposed “walking”, “Main Street”, “public transport” and “car travel” prioritisation.

The inclusion of stormwater tree pits in proposed “cycling” prioritised streets is more difficult and will be influenced by the need for street trees constructed within footpaths and whether a raised kerb is constructed to separate car lanes and cycle paths. Stormwater tree pits could be used for small street trees located within the footpath and when a rumble strip is used to separate vehicle and cycle lanes, hence allowing stormwater runoff to drain towards the kerb closest to the footpath.

Where possible, stormwater tree pits should be located behind the kerb alignment as this configuration minimises the potential impact on overland flow path capacity.

All of the stormwater tree pit configurations presented in Figure 7 to Figure 12 have been shown with underdrains and a connection to the adjacent piped stormwater network. It is noted that any of these configurations could be used as bio-infiltration devices because the only difference between a standard biofiltration and bio-infiltration system is that bio-infiltration systems do not contain an underdrain in the drainage layer.

The stormwater tree pit configurations presented in Figure 7 to Figure 12 can also be used as passive irrigation tree pits. The configuration of passive irrigation tree pits is influenced by the tree species selected. A tree species that is suitable for dry growing conditions will still require the drainage layer and underdrain connection whilst a tree species suitable for wetter growing conditions may allow this to be omitted from the design. The EDD in passive irrigation tree pits will typically be less than stormwater tree pits with 50mm recommended.

Figure 7 Stormwater Tree Pit behind Kerb Alignment

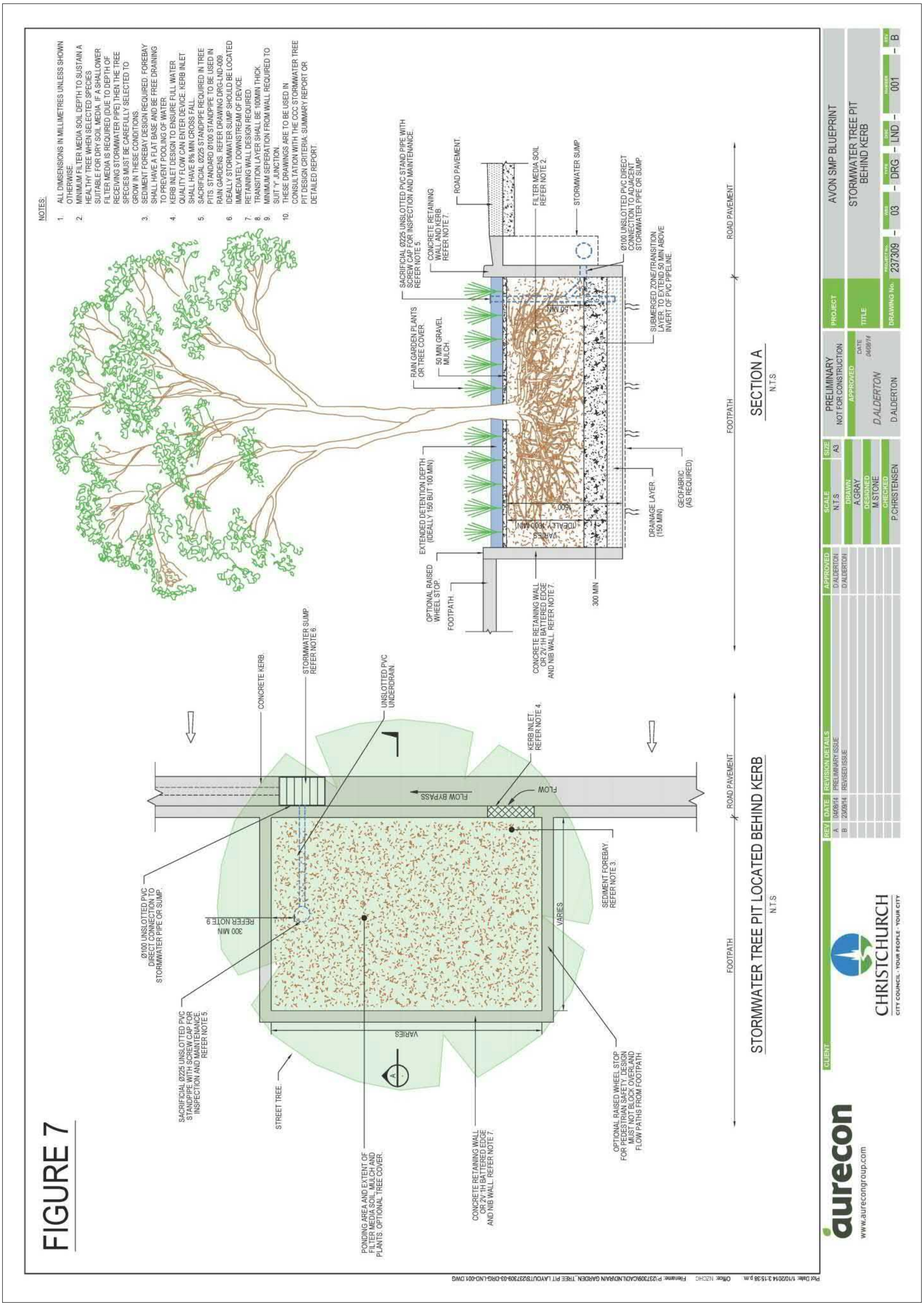


Figure 8 Stormwater Tree Pit in On-Street Parking Bay Build-Out

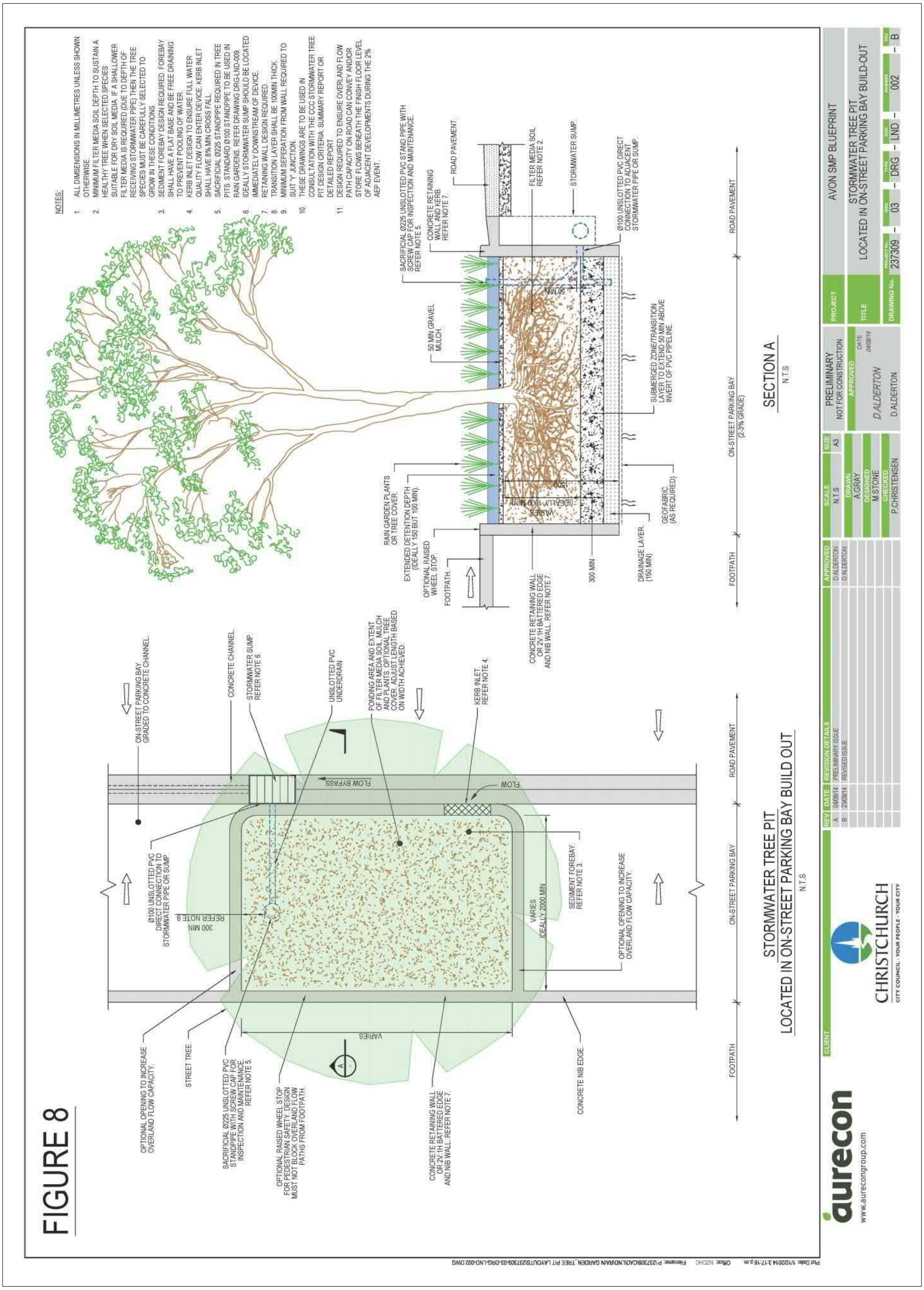


Figure 9 Combined Stormwater Tree Pit and Rain Garden behind Kerb Alignment

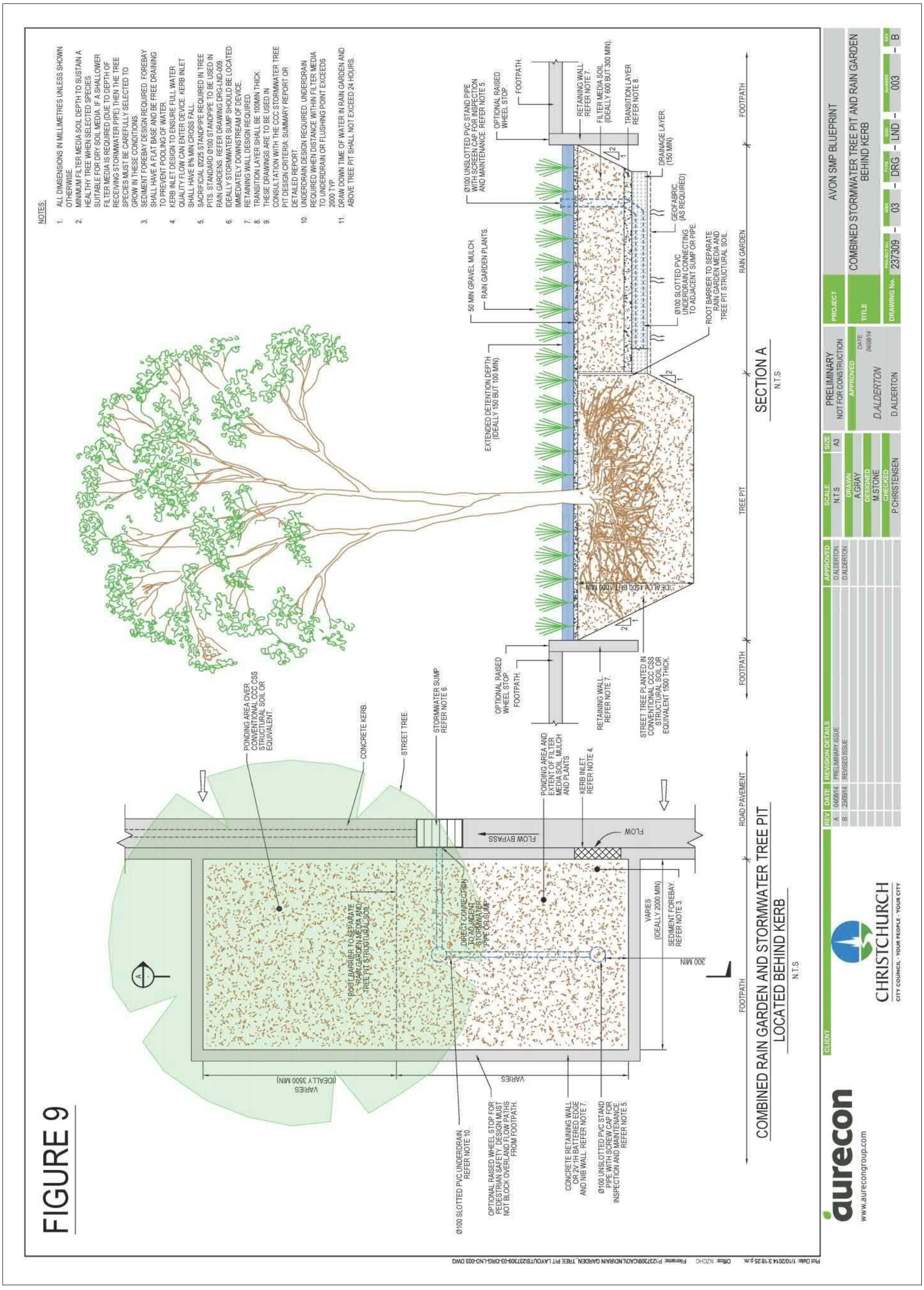


Figure 10 Combined Stormwater Tree Pit and Rain Garden in On-Street Parking Bay Build-Out

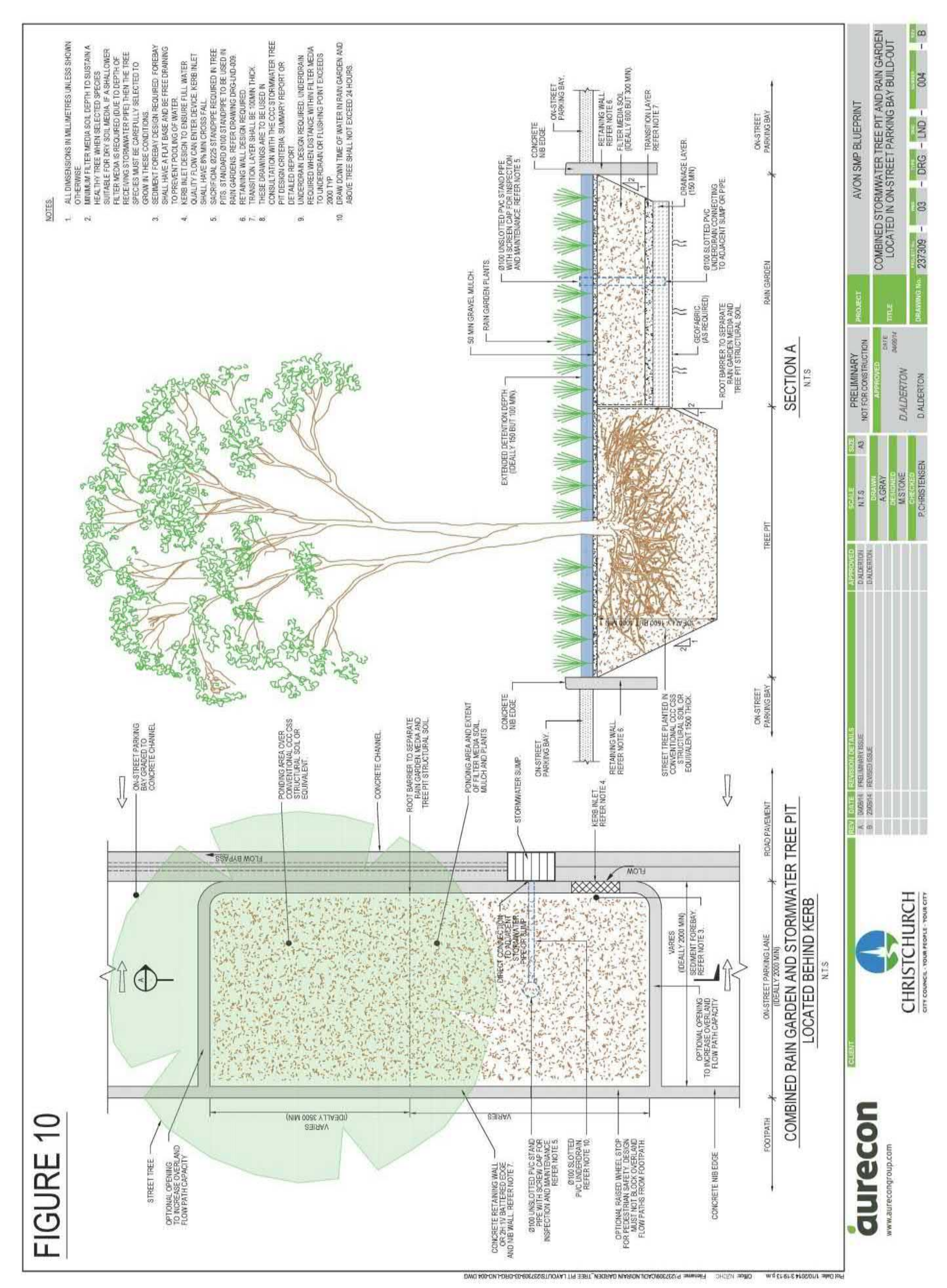


Figure 11 Stormwater Tree Pit in On-Street Parking Bay Graded to Kerb

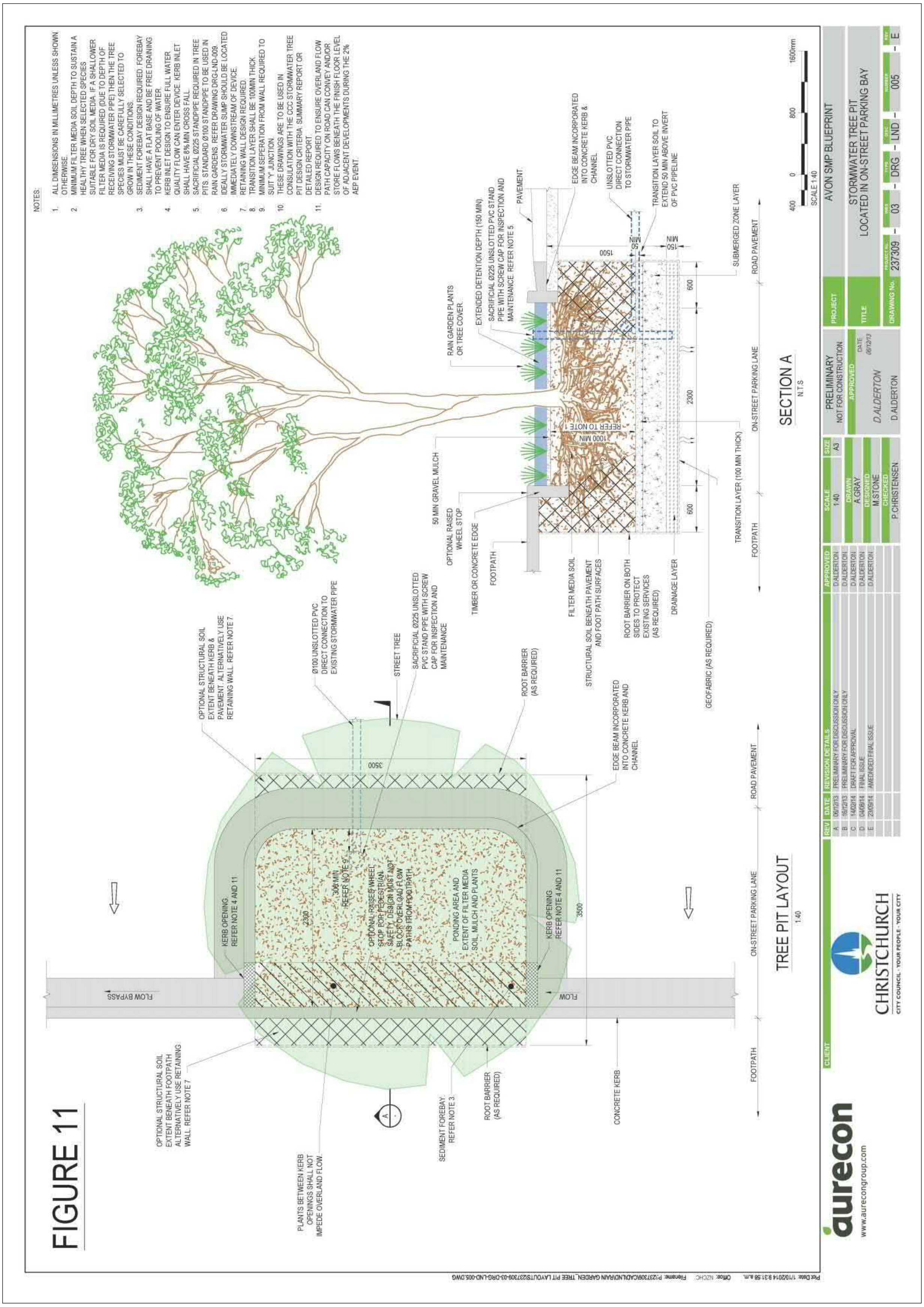


Figure 12 Stormwater Tree Pit (or Rain Garden) in Isolated Traffic Island

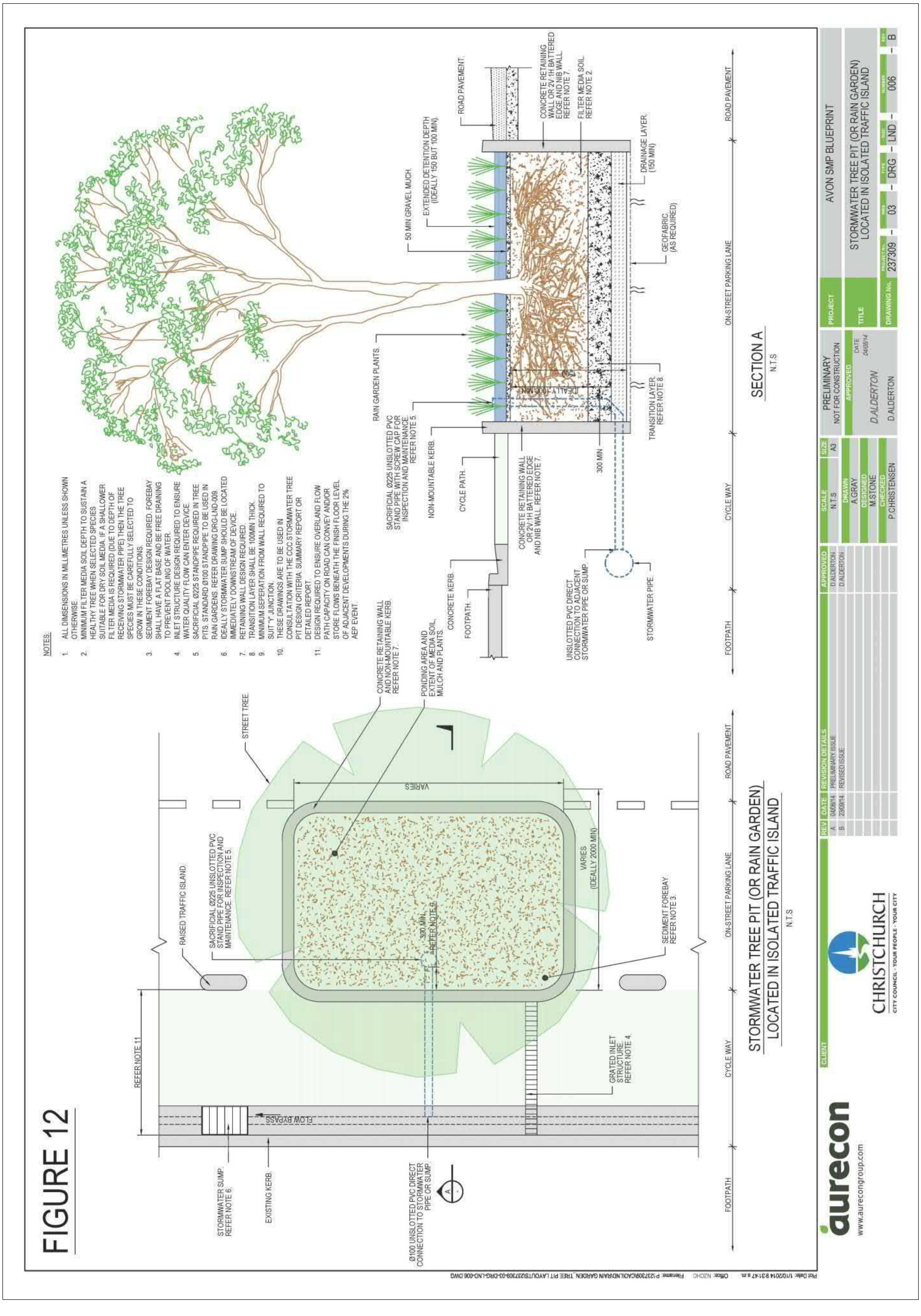


Figure 13 Passive Irrigation Tree Pit in On-Street Parking Bay Graded to Kerb

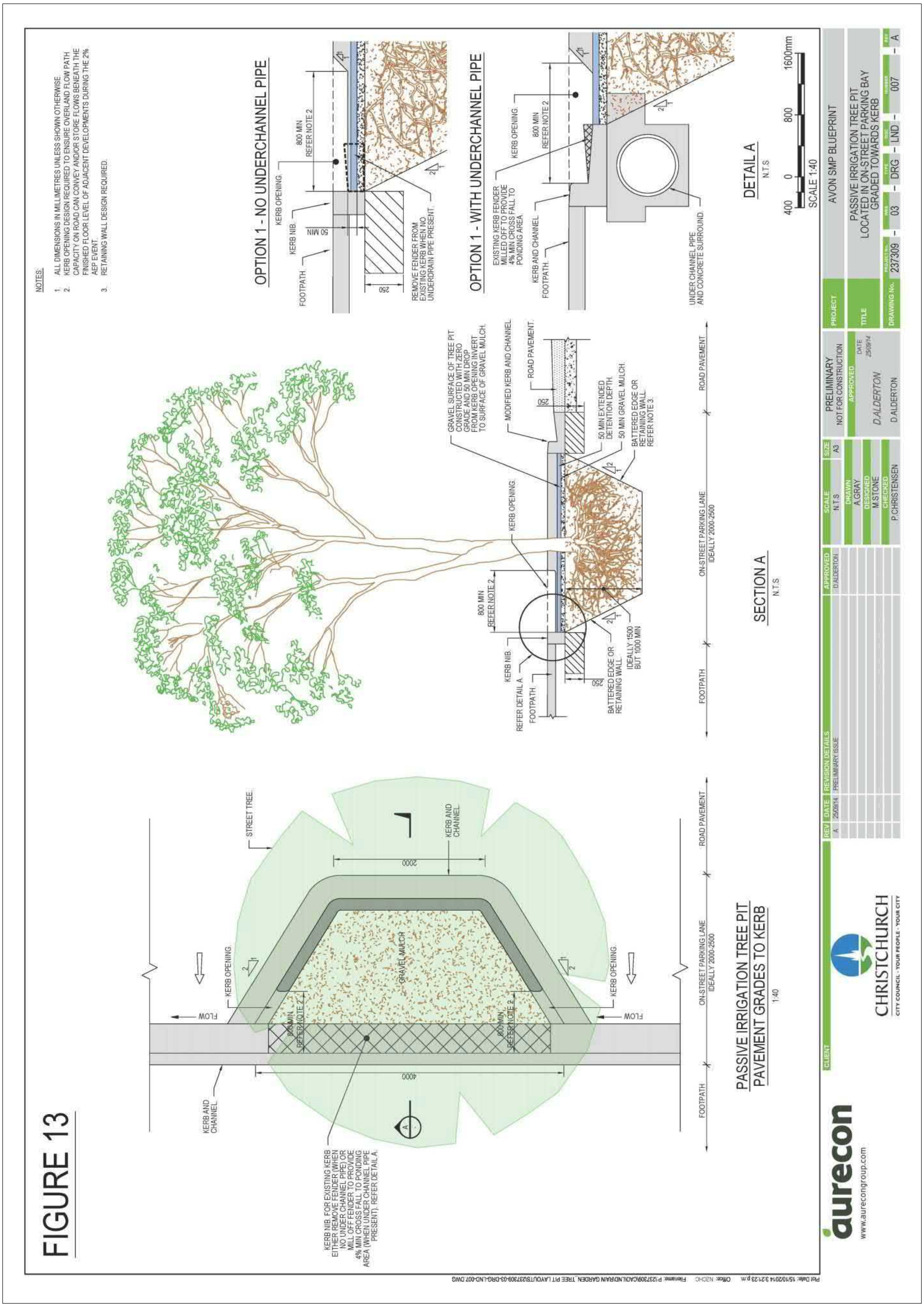


Figure 14 Passive Irrigation Tree Pit in On-Street Parking Bay Graded away from Kerb

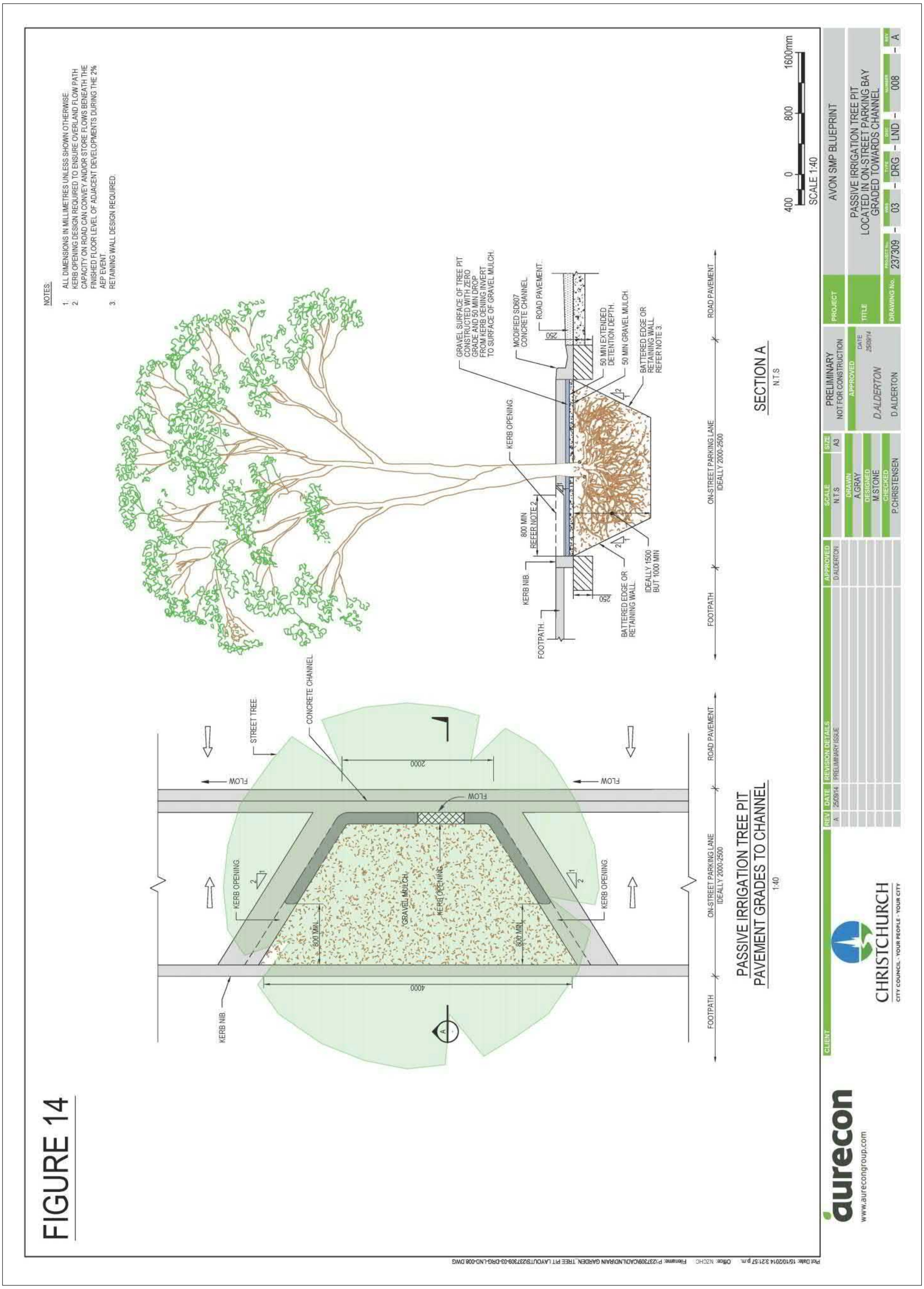
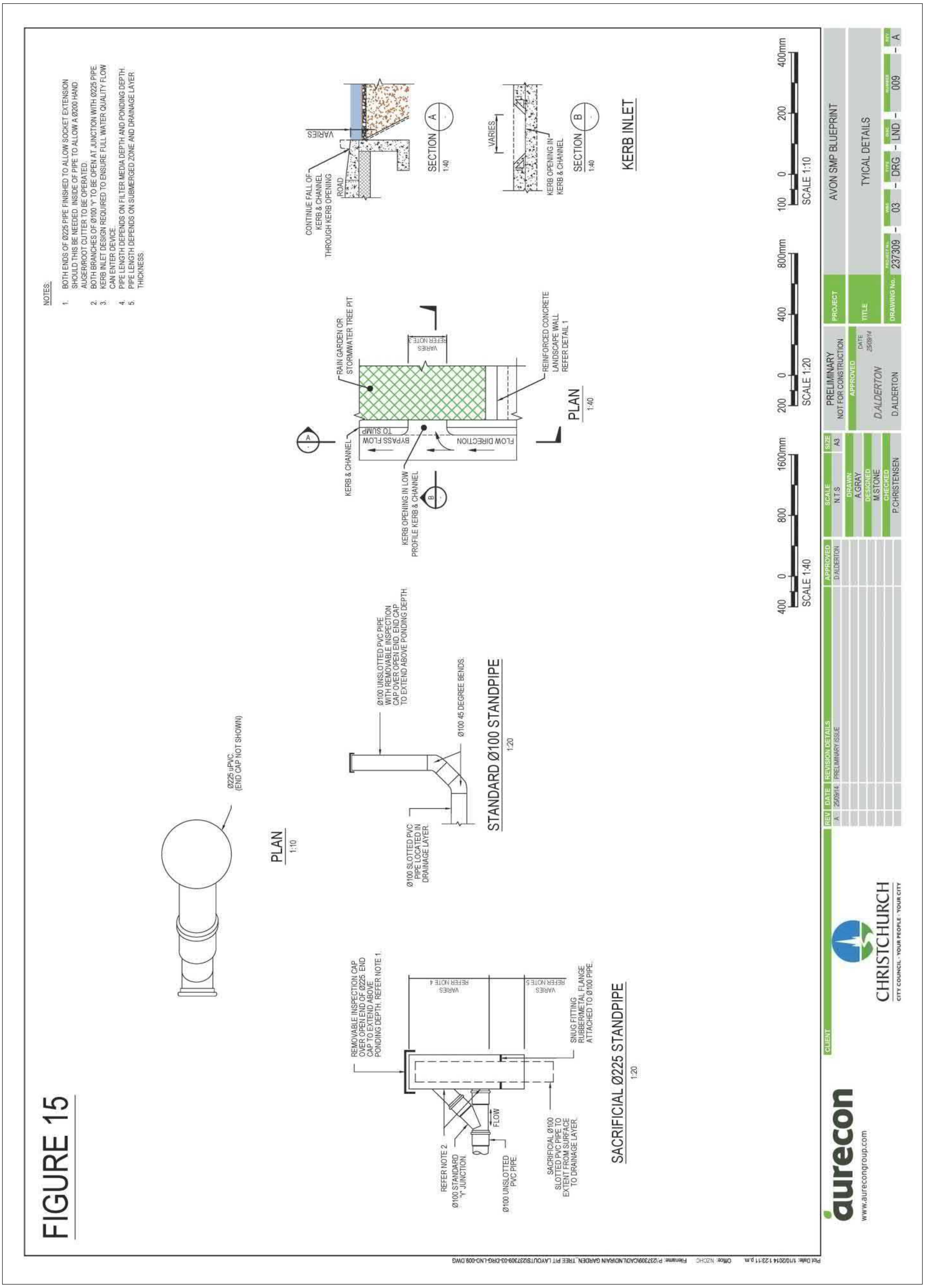


Figure 15 Stormwater Tree Pit Typical Details



4.3 STORMWATER TREE PIT POLLUTANT REMOVAL EFFICIENCY

The pollutant removal for stormwater tree pits is influenced by specific plant traits as well as filter media specification and stormwater tree pit dimensions. A stormwater tree pit with appropriately selected tree species is anecdotally expected to have at least equivalent removal efficiency to that of a rain garden. The pollutant removal efficiency of bioretention devices is influenced by the proportion of stormwater tree pit volume taken up by tree roots and the specific traits of tree roots. Trees typically have a large biomass and it is this large biomass that results in good uptake of pollutants resulting in good stormwater quality outcomes.

Numerous studies have been undertaken to evaluate the potential for using street trees as elements of a stormwater system. One study, *"Are Street Trees and their Soils an Effective Stormwater Treatment Measure*" (Denman, 2006), undertook a pilot scale street tree bioretention experiment to assess the ability of stormwater tree pit bioretention systems in reducing nitrogen loads in urban stormwater runoff. Three tree species (L. confertus, E. polyanthemos and P. orientalis) and three soils of different hydraulic conductivity were tested.

Some of the key outcomes from this study associated with appropriate plant traits and the removal of pollutants from stormwater were:

- The street trees were able to establish successfully in stormwater tree pits with the relatively high frequency of stormwater recharge events used in the experiment.
- Application of stormwater comprising nutrients increased tree height growth and root density compared with potable water.
- Leached nitrogen loads were significantly reduced in systems where a tree was included.
- There was no difference between tree heights and growth in the three soils used.
- Nitrogen effluent loads from planted systems were low compared to the nitrogen input.
- Low saturated hydraulic conductivity soils were more effective in reducing nitrogen losses. However, in practice a high hydraulic conductivity soil would enable infiltration of larger volumes of stormwater.
- Nitrogen loads in bioretention systems were reduced by 82-96%. In comparison, the nitrogen load leached from an unplanted control profile ranged from a 36% reduction to a 7% increase in nitrogen output.
- The study results suggest that street trees and their root zone soils can be successfully used in the stormwater system for nitrogen removal.

Another study *"Plant Traits that Enhance Pollutant Removal from Stormwater in Biofiltration Systems" (2010)* was undertaken by the Facility for Advancing Water Biofiltration (FAWB) at Monash University in Australia. The objectives of the FAWB (2010) study was to determine which plant traits increase the pollutant removal effectiveness of bioretention devices and hence give designers guidance on what types of plants should be used.

Some of the key outcomes from this study associated with appropriate plant traits and the removal of pollutants from stormwater are listed below:

- While planted systems had substantially higher removal of nitrogen and phosphorus, the difference in concentrations of metals between vegetated and unvegetated pots for the species tested was insignificant, with unvegetated soil still removing high proportions of metals (Read et al., 2008). Other studies have also shown that the soil medium in vegetated and unvegetated bioretention systems removes high proportions (e.g. > ~ 90% on average) of influent metals, including Pb, Cu and Zn (Hatt, Deletic, and Fletcher, 2007) and, Sun and Davis (2007). Although some metals are required by plants in trace amounts, they are substantially less important than nitrogen and phosphorus, and concentrations are typically low in plant tissue. The bioretention system filter media therefore plays the dominant role in metal uptake.
- In contrast to metals, plant traits had substantial effects on removal of nitrogen and phosphorus, with no negative effects of stormwater application on plant growth traits and no evidence of fertilisation effects. The removal of nitrogen and phosphorus from stormwater was generally associated with tree root traits.
- Plant traits that correlated most strongly with nitrogen and phosphorus concentration removal were root soil depth, root mass, percent root mass and total root length.
- Root depth relative to filter media depth is particularly important, given that unvegetated soil filters are usually a net source of nitrogen, due to leaching from the media (Hsieh et al, 2005; Davis et al., 2006; Bratieres et al., 2008). Therefore unless the roots extend through the filter media, removal in the upper layers may be undone by unmitigated leaching in the lower layers.
- Plants with thick roots, capable of creating significant macropores in the filter media are likely to be best for protection against clogging of the filter media (Le Coustumer et al., 2007). Conversely, a dense fine root pattern appears to provide the best nutrient removal performance. A combination of different types of plants may therefore be necessary for optimal water quality and hydraulic performance in stormwater tree pits.
- Given the observation that root characteristics are particularly important for nutrient removal, design should also aim to maintain a moisture regime that promotes the ongoing occupation of the entire soil media profile by roots. Zinger et al, (2007) observed that the presence of a saturated zone placed below the filter (in a layer of sand or gravel, with a small percentage of organic matter to provide a carbon source) helped the removal of nitrogen by bioretention systems.
- The suitability of plant species will depend not only on their capacity for pollutant removal, but also on their capacity to tolerate conditions that may negatively impact

plant growth. For example, plants in bioretention systems may be exposed to alternating cycles of wet and dry conditions, ponding and loading of fine sediments.

It is noted that the above studies have only been undertaken on a small community of tree species. Trees grow slowly and therefore have not typically matured in the time period allowable for most laboratory studies. The pollutant removal efficiency of trees is anecdotally expected to improve over time as a tree matures and establishes a full root structure. Therefore the actually pollutant removal efficiency of bioretention stormwater tree pits may be greater than documented in existing laboratory experiments.

4.4 DESIGN PARAMETERS

4.4.1 EDD Recommendation

Extended detention depth (EDD) refers to the maximum depth of stormwater storage on top of the filter media in the stormwater tree pit (as shown in Figure 7 to Figure 12).

The EDD controls the volume of water that is detained for treatment and thus determines the frequency of stormwater bypass.

Implications of varying the depth of the ponding are:

- Deeper ponding = higher overall infiltration rate due to greater driving head.
- Deeper ponding increases the % volume capture per square metre of the stormwater tree pit (meaning a device can be made smaller for equivalent contributing area or a larger rate of pollutant removal can be achieved).
- Safety concerns – greater pool depth and greater fall depth into the device unless plant covers or suitable edge treatment is provided.
- Deeper ponding increases the height of the concrete kerb and/or retaining wall surrounding the stormwater tree pit. This therefore increases the cost of infrastructure.
- Deeper ponding increases the reduction in peak flow and volume for the contributing catchment.
- Depending on the drawdown time, some plants will not cope with long periods of inundation.
- Deeper ponding will reduce the type of tree species that can be planted in the stormwater tree pit.

NZTA recommends an EDD of 0.3m for rain gardens however this value is typically used for larger devices and a lower EDD is typically used for street scale bioretention devices.

Discussions with the City Arborist indicate that a 0.3m EDD will significantly reduce the tree species that could be planted in the stormwater tree pit and that a lower EDD would be preferable. 100 – 150mm EDD is commonly used for stormwater tree pits internationally.

There are a large number of shallow stormwater pipes in Christchurch that are located beneath the kerb and channel with concrete capping as per CSS SD331 and SD332. These areas typically have a depth from kerb invert to stormwater pipe invert of approximately 500mm and therefore a 100mm EDD is typically required in these areas to facilitate the inclusion of bioretention devices. Note that a shallower EDD will increase the footprint of treatment devices.

Note that the EDD is typically the depth *below* the kerb invert level, therefore the depth from the top of kerb or footpath to the top of the filter media will be another 130mm deeper, or 280 mm in total with a 150mm EDD.

There are sometimes concerns that this drop is too high in high pedestrian use areas but in general this can be mitigated through good design. This issue is typically mitigated for stormwater tree pits by installing tree covers / grates over the stormwater tree pit and providing a circular opening for the tree trunk. Tree grates can be easily removed to undertake maintenance of the stormwater tree pit. Tree grates are also useful for weed reduction and maintaining soil moisture in the stormwater tree pit filter media. The more commonly used alternative to tree covers is planting dense vegetation within the stormwater tree pit footprint and installing raised wheel stops or barriers around the stormwater tree pit.

The optimal stormwater tree pit dimensions have been identified as 3.5 x 3.5m by the City Arborist (refer Section 4.4.3). Note that this width (3.5m) is greater than the minimum on-street parking bay width of 2.5m as identified in the CCC City Plan and Infrastructure Design Standard (IDS). To avoid reducing the footpath width, the ponding area for the EDD above the stormwater tree pit is proposed to be 3.5m (long) by 2.3m (wide), with the remaining plant soil width being located beneath the adjacent footpath and/or pavement using a structural soil or structural cells. In areas where a 3.5m wide tree pit cannot be constructed due to constraints such as existing buried services, a rectangular tree pit can be adopted that maintains the same soil volume.

EDD Recommendation

Adopt an EDD of 150mm for stormwater tree pits in the CBD. In areas constrained by shallow stormwater pipes, the EDD can be reduced to a minimum depth of 100mm.

Note that a larger EDD of 300mm could be considered in areas outside the CBD area which have larger contributing catchments and where the selected tree species is not affected by a deeper EDD. Note that adopting an EDD greater than 150mm will significantly reduce the number of tree species that can be used in the stormwater tree pit.

4.4.2 Stormwater tree pit spacing

Discussions with the City Arborist indicate that street trees would preferably be planted at 15-20m spacing on both sides of the street (either alternate or opposite). Trees are proposed to be planted in streets with “walking”, “Main Street”, “public transport” and “car travel” prioritisation as identified in *An Accessible City*.

It is noted that stormwater tree pits do not need to be provided at every street tree and therefore it is possible to alternate between a stormwater tree pit and conventional tree pit if greater tree spacing still achieves the required stormwater treatment requirements. The conventional tree pits between stormwater tree pits can be designed as passive irrigation tree pits to ensure that all street trees are subjected to similar growing conditions, improve tree health and reduce sediment load entering downstream bioretention treatment devices.

The volume capture assessment (refer Section 5.1) indicates that stormwater tree pits can be spaced at a maximum 35m spacing (optimal tree pit dimensions) and still achieve 80% capture of stormwater runoff, when the contributing catchment comprises half the road width pavement, parking bay and footpath only.

<u>Stormwater tree pit spacing recommendation</u>

Street tree planting shall be determined by the City Arborist who has specified a preference that trees be planted at 15-20m spacing on both sides of the street (either alternate or opposite).

Stormwater tree pits shall be spaced at a maximum 35m spacing (optimum layout) to ensure the stormwater treatment objectives are achieved for the CBD area. Note that this spacing assumes stormwater tree pits capture road reserve catchment only.

In areas where stormwater tree pits cannot be placed at 35m maximum spacing due to infrastructure constraints, a larger stormwater tree pit or combined stormwater tree pit and rain garden should be located at the downstream end of the block where possible.

4.4.3 Stormwater tree pit dimensions

The percentage of stormwater runoff volume captured and pollutant removal efficiency have been investigated for the optimal tree pit dimensions (3.5 x 3.5 x 1.5m soil volume and 3.5 x 2.3m ponding area) in this report.

The stormwater tree pit optimal dimensions are presented in Section 4.2. Note that these dimensions are larger than a previous Council design for large build-out and small build-out stormwater tree pit layouts (and which the current design is based on). The original Council designs were conventional tree pits that allowed stormwater to pass along the kerb between the tree and kerb line whereas the stormwater tree pit design documented above are wider to ensure stormwater runoff along the kerb is captured by the stormwater tree pits.

Discussions with the City Arborist indicate that Council preferred stormwater tree pit layout would be the optimum layout; 3.5 x 3.5m in size, with a planting depth of 1.5m. These dimensions are to ensure that the tree has sufficient and appropriate growing medium and space to keep it healthy and stable throughout its life cycle.

As discussed in Section 4.4.1, the EDD above the stormwater tree pit would preferably be 3.5m (long) by 2.3m (wide), with the remaining 1.2m width being located beneath the adjacent footpath and/or pavement. These dimensions ensure that the EDD width can be contained in a typical on-street parking bay width of 2.5m.

In areas where a 3.5 x 3.5m tree pit cannot be adopted due to infrastructure constraints such as existing buried services, a rectangular tree pit can be adopted that maintains the same soil volume. Additional stormwater tree pit width could be provided surrounding the base stormwater tree pit footprint (where possible) to provide additional room for roots to spread laterally to anchor the tree in 3 directions (preferable) or 2 directions (minimum). This could be achieved by providing structural soils on parking/pavement sides of the stormwater tree pit to allow the tree roots to spread laterally into the structural soils. Permeable pavement may be required to allow stormwater runoff to provide moisture for tree roots located beneath hard surfaces.

Stormwater tree pit dimension recommendation

Stormwater tree pits shall be 3.5 x 3.5m in size (optimum layout) with a minimum planting depth of 1.5m in accordance with recommendations from the City Arborist. The 1.5m depth should include the filter media, transition layer and submerged zone (if required).

In areas where a 3.5 x 3.5m tree pit cannot be adopted due to infrastructure constraints such as existing buried services, a rectangular tree pit can be adopted that maintains the same soil volume. A minimum tree pit width of 2m should be adopted and where possible on-street parking bays should be widened to 2.5m to allow a wider tree pit to be adopted.

The open area for ponding of EDD shall preferably be 3.5m (long) by 2.3m (wide). Additional stormwater tree pit width could be provided (where possible) surrounding the base stormwater tree pit footprint to provide additional room for roots to spread laterally to anchor the tree. This is particularly important in areas where the selected stormwater tree pit footprint is smaller than preferred.

A smaller stormwater tree pit ponding footprint would reduce the percentage of stormwater runoff captured (assuming no change in ponding depth or media infiltration rate) due to a resulting reduction in water quality volume that can be captured by the stormwater tree pit. Smaller stormwater tree pit footprints also affect the longevity of these trees as they severely restrict root growth and therefore long term health and stability. Unhealthy roots mean a reduced capacity to function as an environmental asset (i.e. the larger and healthier the root system, the greater the capacity for stormwater pollutant reduction). In addition a large and healthy tree canopy provides much more benefits than a smaller tree (e.g. carbon storage, air purification and pollutant removal, thermal comfort from UV rays, shelter from rain and wind, urban heating reduction, humanising built environments, Garden City image etc.)

4.4.4 Media Infiltration rate

Maintaining adequate infiltration capacity is crucial in ensuring the long-term treatment efficiency of bioretention devices (such as stormwater tree pits). The ability of a bioretention system to detain and infiltrate incoming stormwater is a function of the filter surface area, EDD and the hydraulic conductivity of the filter media (FAWB, 2009).

The media infiltration rate is referred to as k or the coefficient of permeability (m/day) in the NZTA formula. Though not identical both coefficient of permeability and hydraulic conductivity are used interchangeably with infiltration rate in this document.

The filter media in stormwater tree pits is typically similar to rain gardens and therefore similar infiltration rates should be adopted.

The FAWB (2009) guidelines recommend that for a bioretention system with an EDD of 100 – 300mm and whose surface area is approximately 2% of the connected impervious area of the contributing catchment, the resulting hydraulic conductivity will generally be between 100 – 300mm/hr in order to meet best practice targets.

Where the infiltration rates exceed 300mm/hr potential issues such as higher watering requirements during establishment should be considered. Infiltration rates exceeding 600 mm/hr are unlikely to support plant growth due to poor water retention, and may also result in leaching of pollutants (FAWB, 2009).

The infiltration capacity of a bioretention system will initially decline during the establishment phase as the filter media settles and compacts, but this will generally level out and then start to increase as the plant community establishes itself and the rooting depth increases. In order to ensure that the system functions adequately at its eventual (minimum) hydraulic conductivity, a safety factor of two should be used i.e. design shall be undertaken using half the prescribed hydraulic conductivity (FAWB, 2009).

Where possible the filter media in stormwater tree pits (and rain gardens) should be protected from construction stage sediment loads with a sediment forebay.

Infiltration Rate Recommendation

Adopt a minimum initial infiltration rate of 50mm/hr and maximum of 150mm/hr for infiltration media for Avon SMP stormwater tree pit, with an infiltration rate of 30mm/hr used for design purposes. This is equivalent to a coefficient of permeability of 0.72m/day in Equation (1).

It is recommended that Resource Consent conditions should specify a *minimum initial* infiltration rate of 50mm/hr and an operational infiltration rate between 50 and 150mm/hr.

Rejuvenation of the media may need to take place when the infiltration rate falls below 20mm/hr. However, this may not be feasible due to the danger of damaging tree roots and needs to be investigated further.

These are the same infiltration rates adopted for rain gardens in Christchurch.

4.4.5 Media Depth

For stormwater tree pits the media depth is generally governed by planting requirements such as the size of the tree at maturity, species etc. The filter media depth in stormwater tree pits may therefore be greater than in a rain garden.

The FAWB (2009) guidelines recommend a depth of at least 800mm for tree planting.

Discussions with the City Arborist concluded that a 1.5m media depth will be required for stormwater tree pits constructed in the CBD area. This is to ensure that the tree has sufficient area and growth medium for its roots to extend and means a healthier and more stable tree.

It is noted that the deeper media depth (1.5m) will result in a greater pollutant removal and hydrologic control than would be achieved with a lower media depth that would typically be adopted for a rain garden such as 0.6m. The deeper media depth will also provide greater attenuation and volume reduction.

The large number of shallow stormwater pipes within Christchurch will prevent a 1.5m filter media depth from being viable in many locations. In these areas a shallower filter media depth (ideally 1m minimum) should be used and the remaining media depth located within a submerged zone.

The 1.5m stormwater tree pit depth should include the filter media, transition layer and submerged zone (if required).

Media depth recommendation

Adopt a filter media depth of 1.5m. This depth should include the filter media, transition layer and submerged zone (if required).

The minimum filter media depth (excluding the transition layer and submerged zone) shall be 1.0m to ensure tree health is not adversely affected. If this minimum depth cannot be achieved (as will be the case in areas with shallow stormwater pipes) then the use of combined stormwater tree pits and rain gardens or rain gardens only should be considered instead of a stormwater tree pit. The rain garden filter media depth shall ideally be 600mm but 300mm minimum.

Alternatively it may be possible to reduce the filter media depth and select tree species that can withstand roots being saturated for long periods however; provision to prevent roots entering the underdrain and outlet pipe is required.

The transition layer depth shall be a minimum of 100mm.

The drainage layer depth will be determined by the underdrain pipe diameter, minimum pipe cover (50mm minimum) and depth of gravel beneath underdrain (optional to aid infiltration of stormwater into in-situ soil). A 150mm minimum drainage layer depth is recommended for stormwater tree pits with a 100mm diameter underdrain pipe. The base of the drainage layer should be flat.

4.4.6 Filter Media

Bioretention filter media comprises three layers of media: the filter media, a transition layer (100mm deep), and a drainage layer (50mm cover over underdrain) (FAWB, 2009).

The filter media is required to support a range of vegetation types (from ground cover to trees) that are adapted to freely draining soils with occasional wetting (FAWB, 2009). In general, filter media should have an appropriately high permeability under compaction and should be free of rubbish, harmful material, toxicants, declared plants and local weeds. The filter media should contain some organic matter for increased water holding capacity but be low in nutrient content. In the case of natural soils or amended natural soils, the media should be a loamy sand (FAWB, 2009).

The appropriate selection of filter media in a stormwater tree pit is influenced by various factors such as:

- Infiltration rate – should be low enough to ensure adequate contact time for pollutant removal mechanisms to be effective, while being high enough to pass water through fast enough to ensure 80% volume capture. Chemical properties of the media influence the ability to support plant life and influences effluent water quality with potential to balance high hydraulic conductivity/low pollutant-to-media contact time.

- Tree stability – the soil media should provide sufficient stability to prevent the tree from becoming unstable and falling over during high wind events.
- Media composition – the soil media should contain some organic matter for increased water holding capacity but be low in nutrient content.

Stormwater tree pits typically use similar filter media to rain gardens however careful consideration of tree stability needs to be addressed. Whilst small trees are typically stable in the filter media, larger trees may be more problematic and subject to stability issues.

Tree stability is best addressed by providing good soil from the trunk to the drip line of the mature tree canopy. In practice space is limited and good soil is restricted to the stormwater tree pit dimensions which are commonly smaller than the mature tree canopy. This can reduce the size and health of the tree. In this situation, the tree stability can be improved by allowing tree roots to spread laterally to further anchor the tree.

The different soil layers used in stormwater tree pits are discussed separately below.

Filter Media / Plant Soil

The plant soil layer is typically similar to the filter media mix used in rain gardens.

Bioretention filter media typically comprises either a locally available soil-based material that complies with appropriate specifications or engineered filter media. The FAWB (2009) guidelines include a specification to assess the suitability of using a locally available soil-based material for filter media. In practise locally available soil-based material is not typically available and an engineered filter media is typically used.

Engineered filter media generally comprises washed, well-graded sand with an appropriate hydraulic conductivity. There should be no gap in the grading, and the composition should not be dominated by a small particle size range. Clay and silt are important for water retention and sorption of dissolved pollutants; however they substantially reduce the hydraulic conductivity of filter media. It is essential that the total clay and silt mix is less than 3% by weight (FAWB, 2009).

The NZTA (2010) guidelines specify the following (Table 1) particle size distribution for filter media. This composition range should be used for appropriate material specification.

Table 1 Composition Range of Filter Media (NZTA, 2010)

Material	Percentage of total composition	Particle size
Clay and silt	< 3%	< 0.05mm
Very fine sand	5-30%	0.05-0.15mm
Fine sand	10-30%	0.15-0.25mm
Medium to coarse sand	40-60%	0.25-1.0mm
Coarse sand	7-10%	1.0-2.0mm
Fine gravel	< 3%	2.0-3.4mm

The NZTA (2010) guidelines identify that the size fraction influences the structural stability of the material (through mitigation of particles to block small pores and/or slump). The guidelines (NZTA, 2010) recommends that the total clay and silt mix is less than 3% to reduce the likelihood of structural collapse of filter media soils.

The FAWB (2009) guidelines indicate that it may be desirable to increase the organic content e.g. to support particular plant growth (landscape requirements). In these cases, FAWB suggests that it is important to ensure that the nutrient content of the organic matter is kept low to avoid nutrient leaching and that it may be appropriate to provide a layered structure, where only the top layer of the filter media has a high organic content.

The top layer of the filter media should then be ameliorated with appropriate organic matter, fertiliser and trace elements. This amelioration is required to aid plant establishment and is designed in the FAWB guidelines to last four weeks; the rationale being that, beyond this point, the plants receive adequate nutrients via incoming stormwater (FAWB, 2009).

The City Arborist advised that a filter media soil with a total clay and silt mix is less than 3% by weight may not be adequate to maintain adequate health of the tree species to be used in the city. A higher proportion of fines may therefore be required in the sandy loam filter media soil i.e. up to 5-10% by weight. It is noted that a higher proportion of fines will reduce the infiltration rate of the filter media with potential impacts on pollutant removal efficiency. If a higher proportion of fines are adopted for the filter media soil then infiltration testing should be undertaken to ensure compliance with the recommended infiltration rates (Section 4.4.4). However, given that the design infiltration rate is relatively low, it may be that a higher proportion of fines do not negatively impact the effectiveness of the stormwater tree pits. Consideration should also be given to the likelihood of structural collapse of filter media soils if their proportion of fines exceeds 3% by weight.

In the absence of Christchurch specific soil mixes, it is recommended that the NZTA (2010) or Australian (FAWB, 2009) standards be used in the meantime. Further research and review of standards needs to be undertaken to determine the best media mix to be used in Christchurch.

The proportion of organic matter can be 10 – 30% as per the Auckland Council draft rain garden guidelines.

The FAWB guidelines include a specification for the establishment of bioretention filter media and the application of fertilisers.

Transition Layer Material

The transition layer is provided between the filter media layer and drainage layer to prevent filter media from being washed into the underlying drainage layer. The transition layer is typically 100mm (min) thick.

FAWB (2009) recommends that transition layer material should comprise a clean, well-graded sand material containing less than 2% fines.

Drainage Layer Material

The drainage layer collects treated stormwater from the bottom of the stormwater tree pit and conveys it to the underdrain pipes prior to disposal to the adjacent stormwater infrastructure.

FAWB (2009) recommends that the drainage layer material is a clean, fine gravel, such as 2-5 mm washed screenings and that bridging criteria be applied to avoid migration of the transition layer into the drainage layer.

The depth of the underdrain layer is typically determined by the underdrain diameter, minimum pipe cover and the slope of the underdrain (FAWB, 2009). The drainage layer thickness should allow 50mm (min) cover over the underdrain pipe to avoid the sand transition layer entering the underdrain pipe. A 150mm thick drainage layer is therefore commonly used with a 100mm diameter underdrain.

FAWB (2009) also recommends that the perforations in the slotted underdrain pipe should be large enough that the drainage layer cannot fall into the pipes and that a useful check is that the D_{85} (drainage layer) is greater than the pipe perforation opening.

Note that where a gravel-based submerged zone material is used, this also serves as the drainage layer.

The shape of the bottom of the drainage layer is influenced by the design objectives of the bioretention device. If the design objective is to collect as much water as possible (i.e. stormwater harvesting), the bottom of the device should be shaped to define a flow path towards the underdrain (Figure 16, left). This is not common for stormwater tree pits. However, if the goal is to infiltrate stormwater to the surrounding in-situ soil, then the bottom of the device should be flat (Figure 16, centre), particularly if the underdrain pipe is raised above the bottom of the device (Figure 16, right). When a saturated zone is included in the stormwater tree pit, the bottom of the device should be flat.

Figure 16 Drainage Layer Base Profile

Source: FAWB (2009)

Media grading

The grading of material in the filter media layer, transition layer and drainage layers must be selected to prevent migration of fines into the underlying layers.

The purpose of the transition layer is to prevent material in the filter media layer migrating into the drainage layer. The grading of the drainage layer is specified to prevent migration of material from the transition layer into the drainage layer. The grading of the filter media will minimise the depth to which sediment mitigates into the filter media soil.

Structural Soils

Structural soils can be used to prevent compaction of filter media soils located beneath structural finishes such as permeable pavement and pavers. They can therefore be installed around the filter media footprint to allow tree roots to spread laterally beyond the extent of the stormwater tree pit to further anchor the tree.

Structural soils comprise a thoroughly combined mix of aggregate and filler soil to provide an appropriate growing medium, additional tree stability and infiltration rates suitable to achieve the specified stormwater treatment requirements.

The following structural soil composition (Table 2) is from the City of Melbourne Council in Australia. Stormwater tree pits are commonly used throughout Melbourne, including highly urbanised CBD areas of the city, and this structural soil composition is commonly specified and accepted by the City of Melbourne.

The proportion of fines must be carefully specified to ensure that the 50mm/hr minimum infiltration rate can be achieved. Infiltration testing of structural soil media should be undertaken prior to installation.

The City of Melbourne Council has advised the City Arborist (via email communication) that they have found no evidence of the clay washing out of the structural soil filler soil mix. One suggestion was that if the clay element is of concern, plain washed 20-40mm aggregate can be used instead, especially if the trees have access to suitable soil for tree planting at a lower depth. This may be a good compromise, especially since finer sediments and nutrients will be introduced via the stormwater runoff.

Whilst trees will grow in structural soils, the City Arborist commented that they will not grow as well as they would in a filter media or landscape soil with a higher proportion of fines. The smaller proportion of fines will also reduce the pollutant removal efficiency to less than would be achieved by a filter media soil. No studies have been found that investigated the reduction in pollutant removal efficiency that would be achieved by a structural soil however anecdotal evidence suggests that the removal efficiency could be approximately half that of an appropriately specified filter media soil.

Discussions with the City Arborist have concluded that the use of only structural soils in stormwater tree pits is undesirable, and the use of structural soils should be limited to stormwater tree pit footprint located beneath hardstand areas such as road pavement and footpath areas only.

The extent of structural soils in the stormwater tree pits should comprise a 1H:2V batter slope to ensure that load paths from the adjacent pavement surface can be conveyed to the subgrade without resulting in over compaction of the lightly compacted filter media soils. The reduction in pollutant removal efficiency as a result of this structural soil is not expected to be significant.

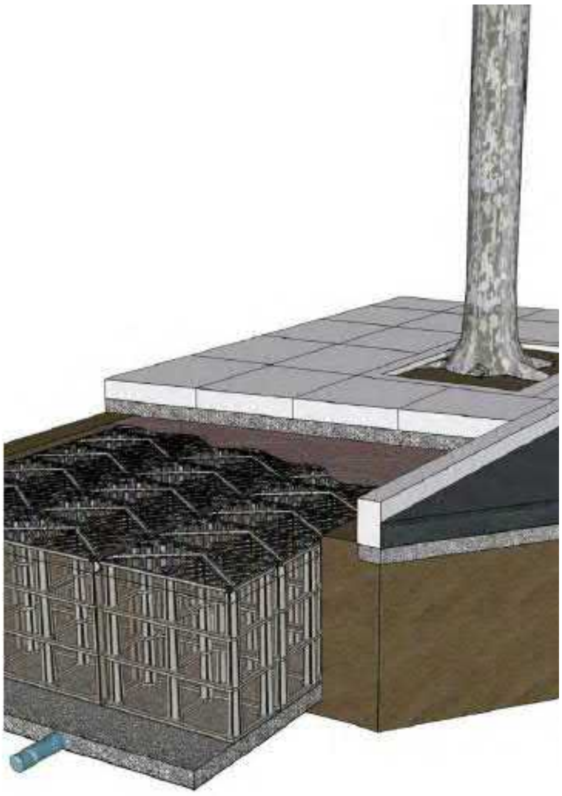
Structural Cells

Some stormwater tree pit designs comprise a smaller opening area to store the EDD than the overall plant soil footprint and this typically results in a permeable hard surface such as permeable pavers/pavement constructed over the filter media layer. Modular structural cells can be used to store lightly compacted filter media soils while supporting traffic / pavement loads above. Maintaining healthy and uncompact soil within structural cells allows the trees to grow and improves the stormwater treatment ability of the stormwater tree pit. Various commercial modular suspended pavement systems are available such as the Silva Cells and Strata Cells systems.

Structural cells can be used as an alternative to structural soils however it is noted that the cost of structural cells is typically greater than that of using a structural soil.

A schematic illustration of some typical structural cell layouts is presented in Figure 17.

Figure 17 Typical Structural Cell Configurations



Deeproot Silva Cell **Strata Cell**

Source: EcoStreets – Integrating Stormwater Source Controls into a Multiple Account Assessment of Urban Infrastructure (Golder Associates, date unknown).

Table 2 Typical Structural Soil Composition

Structural Soil Composition

Structural soils (typically 500 mm deep)

Structural soil mix is to be a thoroughly combined mix of aggregate and filler soil mix in a ratio of 5:1 (by weight), to the structural requirements of the project civil engineer.

Filler Soil Mix

Filler soil shall be a thoroughly combined mix of a clay loam or similar soil and 5% by volume of composted green waste, screened to less than 12mm, with the following properties:

- Organic matter <1% by weight
- PH in water = 5.5 – 6.5
- Electrical conductivity <1.2 ds/m
- Ammonium 20-200 mg/kg
- Phosphorus 10-50 mg/kg

Additives

To the above filler soil components, the following additions are required (to be confirmed during testing of samples for approval).

- Magrilime or a 50/50 lime/dolomite mix to bring PH to 5.5-6.5
- Trace element mix 100 g/m^3
- Potassium nitrate 300 g/m^3
- Nitram (ammonium nitrate) 300 g/m^3
- Superphosphate 300 g/m^3
- Iron sulphate 500 g/m^3
- Controlled release fertiliser (8-9 month osmocote) 1.5 kg/m^3
- Gypsum 300 g/m^3
- Magnesium sulphate (Epsom salts) 150 g/m^3

These additives must be mixed with the filler soil and tested for compliance with the specification.

Aggregate

Shall be 40mm crushed basalt or approved equivalent. Gravel shall be clean and free from clay and other matter. Submit sample for approval. The aggregate shall be of the following particle size distribution.

A.S. SIEVE	PERCENT PASSING (%)
53.0	100
37.5	90-100
26.5	0-75
19.0	< 15
13.2	< 2
9.5	< 2
6.7	< 2
4.75	< 2
2.36	0

Transforming soil mixes must be delivered to site pre-blended. The soil mix must be transported in a moist condition to prevent segregation of components.

Source: The City of Melbourne (provided to the City Arborist)

Discussions with the City Arborist suggest that equivalent local products will be available in Christchurch for all the materials and additives listed in the City of Melbourne structural soil specification.

Submerged Zone Material

The use of a submerged zone in stormwater tree pits is discussed in Section 4.4.7. A submerged zone will saturate filter media (until water can slowly infiltrate into underlying in-situ soil) and this could lead to leaching of pollutants, particularly nutrients (FAWB, 2009). This issue is typically addressed by using a different filter media soil specification in submerged zones.

FAWB (2009) recommends that submerged zone material comprises a mix of medium to course sand and a carbon or a mix of fine gravel and carbon. The carbon source should be a mix of 5% mulch and 5% hardwood woodchips, by volume.

FAWB (2009) also recommends that a 50mm thick layer of plain sand should be used to separate the filter media and submerged zone, to prevent leaching of pollutants from the permanently saturated filter media layer.

A typical recipe for submerged zone material is specified in the FAWB (2009) guidelines.

Media Mix Recommendation

Plant Soil

Follow NZTA (2010) or FAWB (2009) guidelines. Ideally the proportion of silt and clay fines will be less than 3% by weight.

If a proportion of silt and clay fines greater than 3% by weight is required; then infiltration testing of the filter media soil should be undertaken to assess the suitability of the soil for use in the stormwater tree pit.

The proportion of organic matter can be 10 – 30% as per the Auckland Council draft rain garden guidelines.

Transition Layer, Drainage Layer & Submerged Zone Material

Follow NZTA (2010) or FAWB (2009) guidelines.

Structural Soil

Use structural soil composition as specified by the City of Melbourne (Table 2), with adjustments for locally available products as necessary. The proportion if fines must be carefully specified to ensure that the 50mm/hr minimum infiltration rate can be achieved. Infiltration testing of structural soil media should be undertaken prior to installation.

Mulch

The surface of the stormwater tree pit shall include a mulch layer to prevent weeds and help keep soil moist. A non-floatable mulch shall be specified.

A biodegradable weed mat can be used to restrict weed growth until vegetation is fully established.

4.4.7 Submerged Zone

Submerged zones and the benefits of these are discussed in detail in the Rain Garden Design Criteria report. In general a submerged zone contains a permanent pool of water to support the plants and microbial community during extended dry periods, as well as to enhance nitrogen removal (FAWB, 2009).

One of the key benefits of a submerged zone when retrofitting stormwater tree pits into the Christchurch CBD area is that it allows connection (or discharge) at a shallower level than the conventional under drain beneath the stormwater tree pit. This is particularly important in the Christchurch CBD area where there is poorly drained in-situ soil and existing stormwater infrastructure that will need to convey the treated stormwater runoff passing through the stormwater tree pit to the drainage layer.

It is noted that installation of a submerged zone (if required) may restrict the tree species that can be planted in particular regions within the CBD. Therefore the selection of tree species must be undertaken in consultation with determining whether a submerged zone is required to allow discharge of treated stormwater to the existing stormwater infrastructure.

Incorporating a submerged zone into the stormwater tree pit could potentially provide some drought resistance for trees during long periods without rainfall. The FAWB (2009) guidelines indicate that a submerged zone with a depth of 300mm will typically protect against drying for up to five weeks of continuous dry weather and for climates where a longer dry period is likely, the depth of the submerged zone should be increased by 120mm for every additional week of dry weather.

Note that the base of stormwater tree pits could be lined to maintain a permanent submerged zone and prevent water from slowly infiltrating into the in-situ soils. However, this is generally not recommended in Christchurch. In Christchurch this requirement needs to be weighed up against the likelihood of worsening liquefaction from the creation of saturated soil conditions by the submerged zone. In-situ soils needs to be saturated for liquefaction to occur.

If the stormwater tree pit base was not lined, even when a submerged zone is created to allow drainage to the adjacent stormwater infrastructure (at a higher elevation), the submerged zone may be drained slowly via infiltration into the underlying in-situ soils. The Landcare S-map online website indicates that large areas of the CBD comprise imperfectly drained and poorly drained soils with a moderate over slow permeability rate and a permeability rate < 4mm/hr possible in poorly drained areas. This suggests that the submerged zone will slowly drain into the in-situ soil over a period of a few days.

Soil drainage categories for the Avon River catchment and greater Christchurch are presented in Figure 18. The Landcare soil drainage maps can be used to help determine whether the base of stormwater tree pits should be lined or unlined. These maps are available online at http://smap.landcareresearch.co.nz/home

The FAWB (2009) guidelines indicate that a 450mm deep saturated zone has been shown to be optimal; however the feasibility of this figure will be determined by site conditions. A minimum 300mm depth is recommended (FAWB, 2009).

Survey of existing stormwater infrastructure (invert and lid levels) within the city has been provided by SCIRT to allow the typical depth to existing stormwater infrastructure to be estimated. This analysis identified that the majority of existing stormwater infrastructure within the city has a depth to invert typically less than or equal to approximately 1m. Therefore stormwater tree pits constructed in the city will typically have a submerged zone, due to the underdrains having a lower elevation than the existing stormwater infrastructure that they will be connected to.

Submerged Zone Recommendation

Include a submerged zone in stormwater tree pits when the depth of existing stormwater infrastructure (required to receive treated stormwater flows) is shallower than the minimum stormwater tree pit depth (1.8m below the kerb surface level) or when a submerged zone is considered beneficial for tree health.

Determine whether a submerged zone is required before selecting a tree species. A submerged zone may restrict the tree species that can be planted in the stormwater tree pit.

A submerged zone can be included if the saturated zone created would provide additional benefit to the trees health during dry periods. Note that in this case an impermeable liner should be installed on the base of the stormwater tree pit to prevent stormwater infiltrating into the in-situ soil. However, installation of an impermeable liner should be avoided unless absolutely necessary.

Submerged zones will be required in most areas within the city due to the shallow depth to existing stormwater infrastructure.

Figure 19 presents typical stormwater tree pit submerged zone configuration.

Figure 18 Christchurch Soil Drainage (Source: Landcare Research)

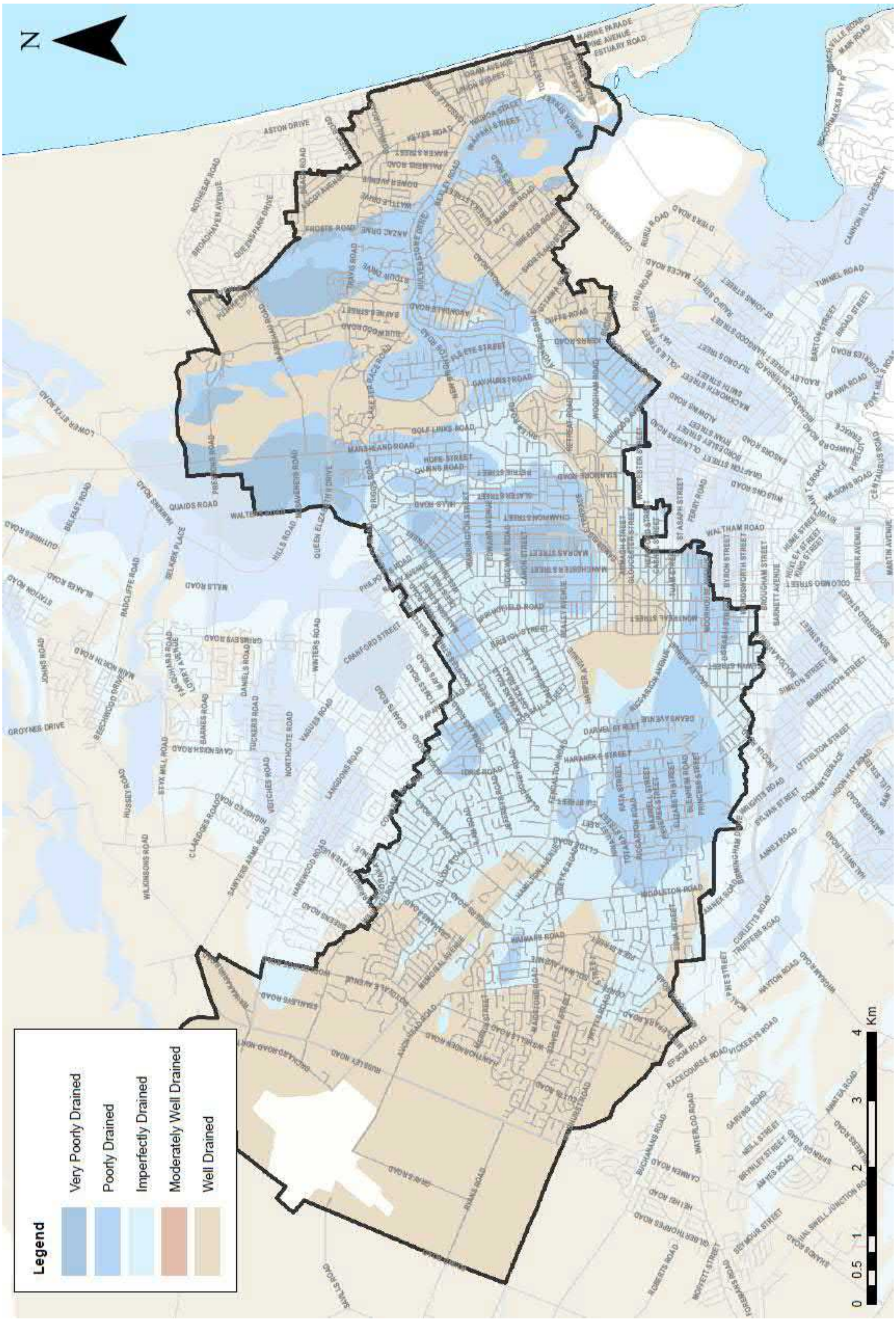


Figure 19 Submerged Zone schematic and installation photo (Brown et al, 2009)

4.4.8 Separation to median groundwater level

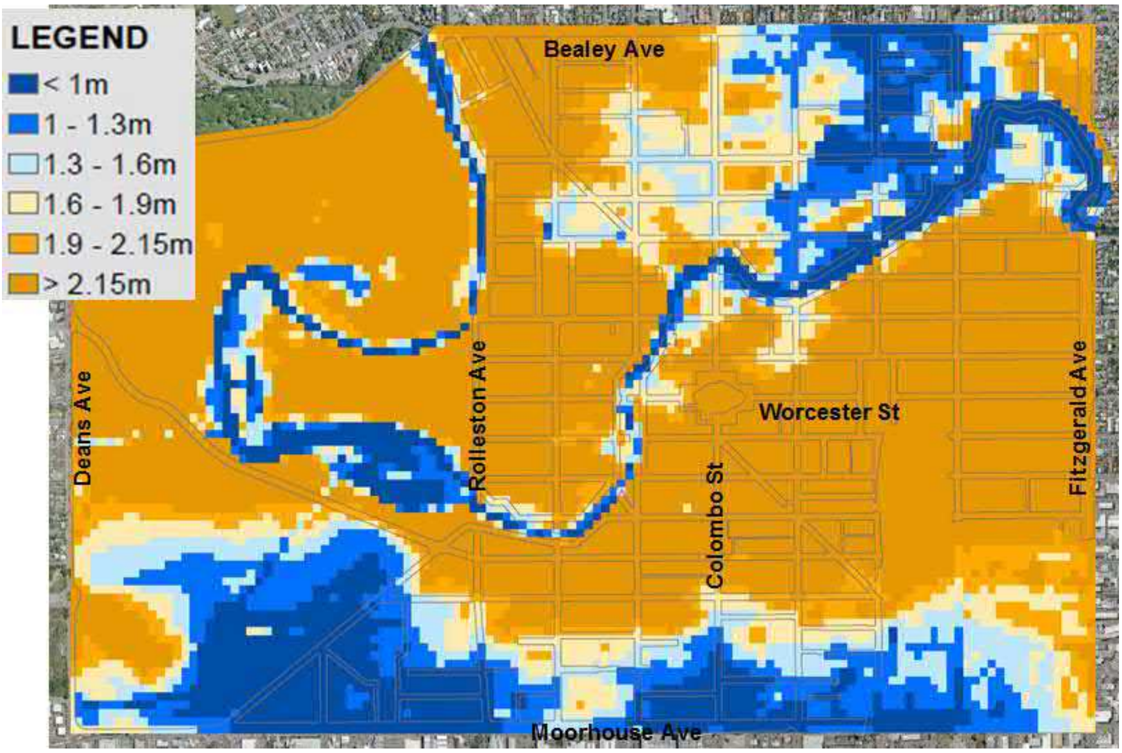
Most literature recommends a minimum depth of 0.3m from the base of a rain garden to groundwater where under drains are installed and 0.6m where there are no under drains. A 0.5m separation to median groundwater level is recommended for stormwater tree pits. It is however noted that in areas where these minimum separations cannot be achieved due to shallower groundwater levels, stormwater tree pits can be used with careful tree species selection.

This means for Christchurch, assuming a 0.15m EDD, 1.5m filter media depth, 0.15m gravel drainage layer and 0.5m separation to median groundwater, the total depth from the ground surface to groundwater needs to be 2.3m.

It can be seen from Figure 20 that the median depth to groundwater in the CBD is generally deeper than 2.10m for a large proportion of the area bounded by Moorhouse Avenue, Bealey Avenue, Deans Avenue and Fitzgerald Avenue. It is however noted that a large area to the south of Saint Asaph Street and to the north of the Avon River in Edgeware and Saint Albans have shallower median depths to groundwater which in places are less than 1m.

Figure 20 presents the expected median depth to groundwater within the CBD; bounded by Moorhouse Avenue, Bealey Avenue, Deans Avenue and Fitzgerald Avenue.

Figure 20 Median Depth to Groundwater within the CBD



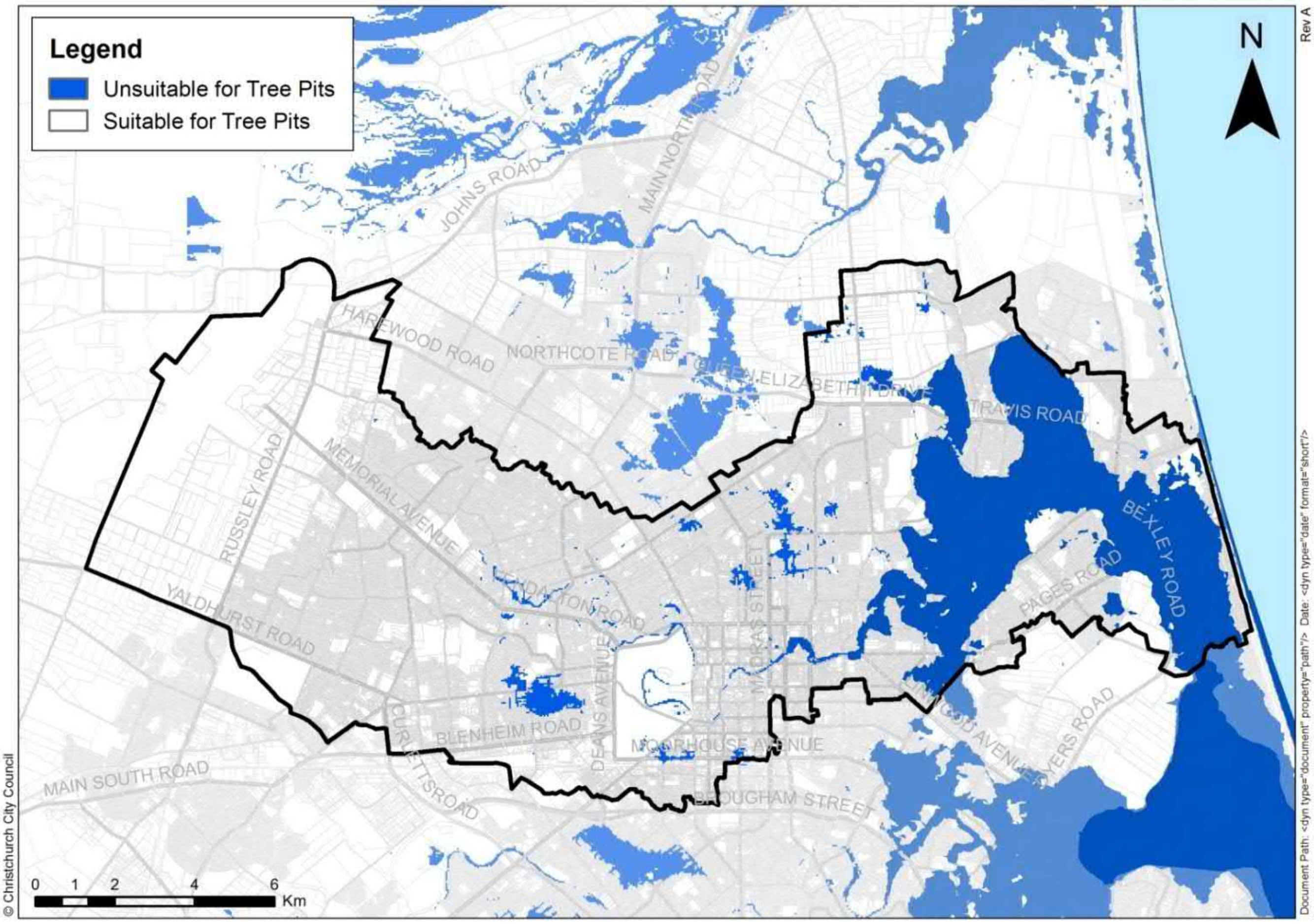
It is noted that groundwater levels in the city are likely to fluctuate over time and therefore the depth to groundwater can be expected to be less than the median depth to groundwater (Figure 20) at times.

The "*Assessment of Median Shallow Groundwater for Christchurch and Surrounding Areas*" (Tonkin & Taylor, 2012) study estimated potential fluctuations in long-term and seasonal groundwater levels. This report identifies that groundwater level fluctuations in the city (eastern zone) are likely to be 0.5m or less due to seasonal fluctuations and <1.2m due to long-term fluctuations. These fluctuations could result in groundwater inundating a larger depth of filter media and therefore tree species should be selected that can tolerate these conditions.

Potential fluctuations in groundwater level should be considered in the design of stormwater tree pits within the city, including appropriate tree species selection.

Consideration should be given to potential impacts of sea level rise on median groundwater levels. Figure 21 presents the areas of Christchurch that are suitable and unsuitable for the use of stormwater tree pits due to the potential impact of sea level rise on median groundwater levels. It may still be possible to include stormwater tree pits in areas identified as 'unsuitable' in Figure 21 if appropriate tree species are selected.

Figure 21 Stormwater Tree Pit Suitability based on Predicted Sea Level Rise Impacts



Recommended Separation to Median Groundwater Level

An underdrain is required for all stormwater tree pits constructed within the city unless they are constructed in areas with well-drained in-situ soil in which the stormwater tree pits can be designed as bio-infiltration devices.

A minimum 0.5m separation to median groundwater level from the base of stormwater tree pit is recommended. Seasonal fluctuations in groundwater levels should be considered whilst designing stormwater tree pits. The Assessment of Median Shallow Groundwater Surface for Christchurch and Surrounding Areas (Tonkin & Taylor, 2012) report identifies a seasonal variability of 1m in the inland zone and 0.5m or less in the eastern/coastal zone.

The median groundwater depth and likely groundwater level fluctuations should be considered whilst selecting appropriate tree species for stormwater tree pits.

Consider the potential impacts of sea level rise on groundwater levels within Christchurch and the corresponding impact on separation to median groundwater levels. This report includes a map identifying areas within the City where stormwater tree pits may be unsuitable without careful design consideration.

4.4.9 Underdrain

In areas where the in-situ infiltration rates are insufficient for discharge to ground, an underdrain is required to collect water draining through the stormwater tree pit and direct the treated stormwater to the piped stormwater network.

An underdrain may not be required in areas with moderately well drained and well drained in-situ soil as identified by the Landcare soil drainage maps (refer Figure 18). In these areas it may be possible to design stormwater tree pits as bio-infiltration systems.

The only difference between a standard biofiltration and bio-infiltration system is that bio-infiltration systems do not contain a collection pipe in the drainage layer (FAWB, 2009).

In areas where bio-infiltration devices are proposed, infiltration testing should be undertaken to confirm that the in-situ soil has an adequate infiltration rate.

The Christchurch CBD area comprises generally poorly drained in-situ soil and a high groundwater table in some areas. Therefore an underdrain will be required for all stormwater tree pits constructed in the CBD (although infiltration through the base can still occur if they are unlined).

An underdrain (typically 100mm diameter) shall be constructed in a 150mm (min) thick gravel drainage layer beneath the stormwater tree pit. Slotted PVC pipes are preferable to flexible perforated pipe, as they are easier to clean and ribbed pipes are likely to retain moisture (when no submerged zone included) which may attract plant roots into the pipe (FAWB, 2009). Pipe socks must be removed prior to installation.

The underdrain must be designed to ensure that perforations in the pipe are adequate to pass the maximum infiltration rate, the pipe has sufficient capacity to convey treated stormwater and that material in the drainage layer will not wash into the perforated pipes (FAWB, 2009).

The underdrain shall comprise the following:

- A slotted PVC pipe (in stormwater tree pit drainage layer) and non-slotted PVC direct connection to the existing stormwater infrastructure, in areas where the existing stormwater pipe is lower than the underdrain elevation.

- A slotted PVC pipe (in stormwater tree pit drainage layer) and non-slotted PVC with upturned elbow direct connection to the existing stormwater infrastructure, in areas where the existing stormwater pipe is higher than the underdrain elevation or a saturated zone is required.

An un-slotted standpipe (flushing point) should typically be provided for each stormwater tree pit. The flushing point should extend to the surface of the stormwater tree pit to allow inspection and maintenance, is typically included in a protective pipe sleeve and should be unperforated and capped.

In order to promote infiltration of stormwater into the in-situ soil, the collection pipe can be raised from the bottom of the drainage layer (Figure 16).

The underdrain shall be installed at constant zero grade within the drainage layer or at a 0.5% grade where required.

An underdrain collection pipe is not strictly necessary in a stormwater tree pit with a submerged zone as inclusion of an upturn elbow (riser) outlet confines exit flow to be via this path and the drainage layer can act as a surrogate collection pipe. The riser outlet should extend to the surface of the stormwater tree pit to allow inspection and maintenance (FAWB, 2009).

Recommended underdrain specifications

The underdrain (when required) shall comprise a slotted PVC (typically 100mm diameter) pipe constructed in a 150mm minimum thick gravel drainage layer beneath the stormwater tree pit. Slotted PVC pipes are preferable to flexible perforated pipe. The underdrain shall be installed at constant zero grade within the drainage layer.

A non-slotted direct connection shall be made to existing stormwater pipes adjacent the stormwater tree pits.

A standpipe (flushing point) should typically be provided to facilitate underdrain inspection and maintenance.

An underdrain collection pipe is not strictly necessary in a stormwater tree pit with a submerged zone as inclusion of an upturn elbow (riser) outlet confines exit flow to be via this path and the drainage layer can act as a surrogate collection pipe. The riser outlet should extend to the surface of the stormwater tree pit to allow inspection and maintenance.

An underdrain may potentially be omitted from the stormwater tree pit in areas with moderately well drained and well-drained soil as identified on the Landcare soil maps. Infiltration testing should be undertaken to ensure that the in-situ infiltration rate (with a factor of safety of 3 applied as per the CCC WWDG) exceeds the design infiltration rate of the filter media.

4.4.10 Root barriers

Stormwater tree pits are typically sited so they are clear of existing and proposed utility services. However, this may not be possible in the CBD due to the large number of existing utility services present and the need to generally achieve a consistent spacing between street trees.

When the stormwater tree pits cannot be constructed sufficiently clear of existing utility services, tree root barriers may be required to minimise potential damage from street trees.

The City Arborist advised that the City of Melbourne have used a weak concrete mix as an effective root barrier in stormwater tree pits. This could be considered as an alternative to root barriers in locations in the city where root barriers are not appropriate.

Existing utility services (protected in a sleeve) should not pass through the stormwater tree pit filter media as they could be damaged by root growth or if an established tree were to overtop. Existing utility services could pass beneath stormwater tree pits if permitted by the service provided.

Tree root barrier recommendation

Tree root barriers shall be provided for stormwater tree pits when the minimum offset between utility services cannot be achieved. Root barriers will typically only be required along the pavement and footpath edges of the stormwater tree pit.

Tree root barriers shall be constructed in accordance with the Council Construction Standard Specification requirements. The tree root barriers shall extend from the base of the stormwater tree pit to the surface elevation. Geofabric is not required on stormwater tree pit edges where root barriers are installed.

4.4.11 Tree grates

As discussed in Section 4.4.1, provision of a 150mm EDD beneath the kerb opening results in a 280mm drop from the adjacent footpath to the surface elevation of the stormwater tree pit. This can create a safety hazard, particularly in areas with heavy pedestrian movement such as occurs within some areas of the Christchurch CBD.

Tree grates can be provided over stormwater tree pits to ensure that a flat surface is created, with a circular opening provided for the tree trunk.

They provide space for the tree while allowing pedestrian traffic over the tree planting area and also help to suppress weeds and trash accumulation in the tree planting area.

Some tree grate products can allow the tree opening to be enlarged in increments to accommodate tree growth, protecting the tree from injury. This is the recommended design for any tree grate as grates that do not have this capability often end up injuring the tree, affecting its health and reducing its effective life span. Standard opening sizes are provided for commercial products but very large openings can be constructed to accommodate large tree trunks.

The Council Construction Standard Specifications provides standard drawings for a small tree grate (920 x 920mm) and a large tree grate (1,680 x 1,680mm). A 460mm diameter opening is provided for the tree trunk opening. Standard drawings are also provided for tree grate foundations, required to support the tree grates.

The minimum stormwater tree pit dimensions within the CBD (3.5 x 2.3m opening) would require a specific design to be prepared for these larger stormwater tree pit dimensions.

Tree grate openings are typically sized to accommodate the diameter of the established tree trunk with some clearance around the tree to prevent damage. This also minimises the safety risk to the public associated with falling into the tree grate opening.

Figure 22 presents photos of some existing stormwater tree pits.

Figure 22 Typical Stormwater Tree Pits and Tree Grates

Little Burke Street, Melbourne

Little Burke Street, Melbourne

University of Sydney

Waitangi Park, Wellington

Stormwater tree pit finishes could comprise one of the following:

- Tree grate covering the entire open ponding area of the stormwater tree pit.

- Tree grate covering a smaller open area of the stormwater tree pit and comprising a structural surround such as permeable pavers or pavement.
- Open ponding area without a tree grate and planted with vegetation. Raised wheel stops or barriers should be included on all sides of treatment device adjacent footpaths.

A tree grate covering a smaller open area is not recommended from a stormwater treatment objective as this reduces the volume of EDD that can be stored and therefore reduces the percentage of stormwater runoff volume captured and pollutant reduction. The use of a structural surround such as permeable pavement over the stormwater tree pit will require the use of a structural soil layer or structural cells within the stormwater tree pit to prevent the filter soil becoming compacted.

The most suitable stormwater tree pit finishes are either an open ponding area without a tree grate (and raised wheel stops or barriers included) or a tree grate covering the entire open area. The selection of stormwater tree pit covering will be influenced by the desired landscape objectives and pedestrian safety considerations etc. The final design will therefore vary from street to street within the CBD.

Stormwater tree pit surface finishing recommendation

The surface finishing of stormwater tree pits should either comprise an uncovered open area (with rain garden planting) or a tree grate covering the entire open ponding area.

Stormwater tree pits with an open surface (i.e. no tree cover) should have raised wheel stops on all edges adjacent the footpath for pedestrian safety.

The stormwater tree pit surface should be covered with a non-floatable mulch.

If a weed mat is used it should be biodegradable.

4.4.12 Tree Species Selection

Filter media soil is typically a loamy sandy so although it will be saturated frequently it will dry out relatively quickly (approx. 1 day) and hence reduce the moisture content of the soil. Careful selection of tree species is required to ensure that they will tolerate these growing conditions to ensure the stormwater treatment potential is maximised and the tree remains healthy.

As discussed in Section 4.3, the suitability of tree species will depend not only on their capacity for pollutant removal, but also on their capacity to tolerate conditions that may negatively impact plant growth. For example, plants in bioretention systems may be exposed to alternating cycles of wet and dry conditions, ponding and loading of fine sediments.

The pollutant removal for stormwater tree pits is influenced by specific plant traits. Tree species should be selected that have these traits where possible. Specific plant traits associated with the successful removal of pollutants from stormwater include root soil depth, root mass, percent root mass, total root length and root depth relative to filter media depth.

Tree roots could potentially spread in search of water and therefore result in damage to adjacent infrastructure and utility services. Design measures can be used to prevent infrastructure damage from tree roots, such as minimum clearances, tree root barriers and filter media soil specification. These measures are not always successful. The selection of tree species should carefully consider the likely size of the root structure when the tree reaches its full size.

A list of suitable tree species has been prepared by the City Arborist that comprises wet, dry and hard surfaced areas. This list is presented in Table 3. Note that the height and width ranges are the sizes Council reasonably expect these species to grow to in a street / car park / hard surface environment. The City Arborist identified that the trees are being planted in heavily modified environments when compared to the trees' natural growing situations. The height sizes in the plant identification books are for perfect growing conditions, which just don't occur in a highly modified, intensified and urbanised area.

It is noted that the listed tree species suitable for car parks, paved surfaces and building conditions are all suitable for the loamy sand filter media soil encountered in stormwater tree pits. The tree species suitable for dry soil conditions are most appropriate for stormwater tree pits without a submerged zone or high groundwater level, whereas the tree species suitable for wet soil conditions are most appropriate for stormwater tree pits with a submerged zone.

Table 3 Suitable Tree Species (Source: CCC)

Common Name	Scientific Name	Height Range (m)	Canopy Spread Range (m)
Tree species suitable for wet soil conditions			
Swamp cypress	Taxodium distichum	15m - 20m	6m - 10m
Moosewood	Acer pensylvanicum	15m - 20m	10m - 15m
Red maple	Acer rubrum	15m - 20m	10m - 15m
Tupelo	Nyssa sylvatica	15m - 20m	6m - 10m
Kahikatea/white pine	Dacrycarpus acrydioides	10m - 15m	6m - 10m
Hills oak	Quercus elipsoidalis	15m - 20m	10m - 15m
English oak	Quercus robur	15m - 20m	10m - 15m
Black birch	Betula nigra	15m - 20m	10m - 15m
Common ash	Fraxinus excelsior	15m - 20m	10m - 15m
Green ash	Fraxinus pennsylvanica	15m - 20m	10m - 15m

Common Name	Scientific Name	Height Range (m)	Canopy Spread Range (m)
Dawn redwood	Metasequoia glyptostroboides	15m - 20m	6m - 10m
Tree species suitable for dry soil conditions			
Field maple	Acer campestre	10m - 15m	10m - 15m
Norway maple	Acer platanoides	15m - 20m	10m - 15m
Hornbeam	Carpinus betulus	10m - 15m	10m - 15m
Hop hornbeam	Ostrya carpinifolia	10m - 15m	6m - 10m
Mediterranean hackberry	Celtis australis	15m - 20m	6m - 10m
American hackberry	Celtis occidentalis	15m - 20m	6m - 10m
Bay laurel	Laurus nobilis	10m - 15m	6m - 10m
Persian ironwood	Parrotia persica	3m – 10m	6m - 10m
Japanese stone oak	Lithocarpus edulis	3m - 10m	6m - 10m
Algerian oak	Quercus canariensis	15m - 20m	10m - 15m
Hills oak	Quercus elipsoidalis	15m - 20m	10m - 15m
Turkey oak	Quercus cerris	15m - 20m	10m - 15m
Cork oak	Quercus suber	15m - 20m	10m - 15m
Evergreen oak	Quercus ilex	15m - 20m	10m - 15m
Arizona ash	Fraxinus velutina	15m - 20m	10m - 15m
Tree species suitable for car parks, paved surfaces and building conditions			
Common lime	Tilia x europaea	15m - 20m	10m - 15m
Large leaved lime	Tilia platyphyllos	15m - 20m	10m - 15m
Silver lime	Tilia tomentosa	15m - 20m	10m - 15m
Tulip tree	Liriodendron tulipfera	15m - 20m	15m - 20m
Mediterranean hackberry	Celtis australis	15m - 20m	6m - 10m
American hackberry	Celtis occidentalis	15m - 20m	6m - 10m
Field maple	Acer campestre	10m - 15m	10m - 15m
Norway maple	Acer platanoides	15m - 20m	10m - 15m
Variegated Norway Maple	Acer platanoides ‘Drumondii’	10m - 15m	10m - 15m
Red maple	Acer rubrum	15m - 20m	10m - 15m
Fraxinus 'Green Glow'	Fraxinus 'Green Glow'	15m - 20m	10m - 15m
Green ash	Fraxinus pennsylvanica	15m - 20m	10m - 15m
American ash	Fraxinus americana	15m - 20m	10m - 15m

Common Name	Scientific Name	Height Range (m)	Canopy Spread Range (m)
Common ash	Fraxinus excelsior	15m - 20m	10m - 15m
London plane	Platanus acerifolia	15m - 20m	10m - 15m
Oriental plane	Platanus orientalis	15m - 20m	10m - 15m
Algerian oak	Quercus canariensis	15m - 20m	10m - 15m
English oak	Quercus robur	15m - 20m	10m - 15m
Liquidambar 'Worplesdon'	Liquidambar 'Worplesdon'	15m - 20m	10m - 15m
Tupelo	Nyssa sylvatica	15m - 20m	6m - 10m

The City Arborist also identified that Metasequoia glyptostroboides (dawn redwood), Nyssa sylvatica (tupelo), Taxodium distichum (swamp cypress), Acer rubrum (red maple) and Quercus phellos (willow oak) tree species are suitable for stormwater tree pits with a shallow free draining upper layer and deeper submerged zone layer.

Tree species selection recommendation

Use tree species as identified by the City Arborist.

Tree species must be able to tolerate conditions that may negatively impact plant growth. For example, plants in bioretention systems may be exposed to alternating cycles of wet and dry conditions, ponding and loading of fine sediments. Filter media is typically sandy and will dry out relatively quickly.

Tree species must be able to tolerate the removal and replacement of the upper 100mm of filter media as this may be required to reinstate the infiltration capacity of the filter media.

Tree species should be determined by biodiversity considerations, site conditions (e.g. median groundwater level, presence of submerged zone), design objectives (e.g. stormwater treatment, habitat creation), and the surrounding landscape (e.g. aesthetic conditions, shade).

4.4.13 Drawdown Time

Drawdown time (t_{rg}) refers to the time for the EDD to infiltrate through the soil until ponding area is dry. NZTA recommends a one day drawdown time in areas frequented by pedestrians, and two days in less frequented areas.

Drawdown Time recommendation

Adopt a design drawdown time of one day (24 hours) for stormwater tree pits within the CBD area.

4.4.14 Vegetation Specification

Plants improve stormwater tree pit performance by increasing the removal of nutrients, particularly nitrogen, as well as help to maintain the long-term infiltration capacity of bioretention systems. However, some species are more effective than others in their ability to adapt to conditions within a biofilter, along with their influence on the nutrient removal and hydraulic conductivity of the biofilter. Plants also contribute to the reduction of outflow volumes via evapotranspiration, which in turn can help the local microclimate. Vegetation should therefore be carefully specified according to the system objectives as well as the local climate (FAWB, 2009).

Suitable species for stormwater tree pit vegetation should be:

- Tolerant of drought, freely draining filter media and variable periods of inundation.
- Have extensive root structures and should not be shallow rooted. Ideally the roots should penetrate the entire filter depth. Dense linear foliage with spreading growth form is desirable, while clumped structures such as bulbs or large corms should generally be avoided (because they can promote preferential flows around the clumps, leading to erosion) (FAWB, 2009).
- Frost and shade tolerant.

The planting density of other vegetation should be high (at least 10 plants/m^2 for sedges and rushes) to increase root density, protect surface porosity, promote even distribution of flows, increase evapotranspiration losses (which helps to reduce runoff volume and frequency), and reduce the potential for weed invasion (FAWB, 2009).

Other vegetation specification considerations identified in FAWB (2009) include:

- Plants in areas of the stormwater tree pit furthest from the inlet may not be inundated during small rain events and may therefore need to be particularly hardy and tolerant of drying conditions. Conversely, plants near the inlet may be frequently inundated, and potentially impacted by higher flow velocities, and so plants capable of handling these conditions should be selected.
- Vegetating the stormwater tree pits with a range of species increases the robustness of the system, because it allows species to "self-select" i.e., drought tolerant plants will dominate in further areas from the inlet, while plants that prefer wetter conditions are

likely to thrive near the inlet. Also this allows the stormwater tree pit to maintain some vegetation in the event that one species dies off.

- When gravel mulch is used, high planting densities should be used, to compensate for the reduced spread of plants caused by the gravel mulch.

<u>Vegetation specification recommendation</u>

Used plant species as identified by a landscape architect based on biodiversity considerations, site conditions, design objectives, stormwater treatment, and landscape considerations.

Plant species must be able to tolerate conditions that may negatively impact plant growth. For example, plants in bioretention systems may be exposed to alternating cycles of wet and dry conditions, frost, ponding and loading of fine sediments. Filter media is typically sandy and will dry out relatively quickly.

The planting density should be high (at least 10 plants/m^2 for sedges and rushes) to increase root density, protect surface porosity, promote even distribution of flows, increase evapotranspiration losses (which helps to reduce runoff volume and frequency), and reduce the potential for weed invasion. Shrubs should be planted at a density of <1 plant/m^2 and according to landscape requirements.

4.4.15 Liner Specification

Stormwater tree pits are typically lined with either an in-situ surrounding soil with a naturally low hydraulic conductivity such as clay or in some cases with a flexible membrane. Due to the presence of natural silty soils, shallow median groundwater level and therefore the chance of liquefaction clogging the engineered drainage layers in future earthquake sequences, it is recommended that stormwater tree pits in areas at risk of liquefaction consider the use of a geofabric liner. However, the use of liners is generally not recommended in Christchurch.

A heavy duty flexible membrane, such as high-density polyethylene (HDPE), can be used to line the base of the drainage layer and sides of the stormwater tree pit (FAWB, 2009). Typically the sides of stormwater tree pits are not lined, as flow will preferentially be vertical and there is little opportunity for infiltration through the sides of stormwater tree pits.

Geofabric or root barrier may be used as the flexible membrane where these design elements are required provided they achieve the desired design outcomes of both items in the selected product.

<u>Liner recommendation</u>

A heavy duty flexible membrane, such as high-density polyethylene (HDPE), can be used to line the base of the drainage layer and sides of the stormwater tree pit to above the submerged zone water level. This liner will prevent the submerged zone from draining (improving plant health during dry periods) but will also prevent recharge of groundwater and may potentially worsen liquefaction from the creation of saturated soil conditions by the submerged zone. However, the use of a liner is generally not recommended in Christchurch.

If a submerged zone is not required for the tree species selected then a liner should be omitted to allow recharge of groundwater. However, the base and sides of stormwater tree pits could be lined in areas at risk of liquefaction.

Stormwater tree pits without a submerged zone but in areas at risk of liquefaction could be lined with a geofabric to allow recharge of groundwater but to prevent liquefaction entering the stormwater tree pits.

When stormwater tree pits are constructed adjacent to existing services a root barrier should be included to prevent damage to services. In these areas the root barrier can be used instead of the geofabric liner.

4.4.16 Stormwater Tree Pit Stormwater Inlet and Flow Bypass

Likely Stormwater Tree Pit Configurations

Where possible stormwater tree pits should be located behind the kerb alignment to ensure they can operate as off-line treatment devices with high flow bypassing the treatment devices when the EDD storage is full. However, stormwater tree pits can be incorporated into the kerb layout in numerous configurations. Some configurations that are likely to occur in the Christchurch CBD include:

- <u>Stormwater tree pit constructed in the footpath behind the kerb</u>: This layout will ensure that the overland flow path is not impeded by the stormwater tree pit. Low flows can enter the stormwater tree pit via a single kerb opening on the kerb side and high flows will bypass the stormwater tree pit when the capacity of the EDD area is exceeded. Refer Figure 7 and Figure 9.

- <u>Stormwater tree pit constructed in the on-street parking bay with on-street parking bay pavement regraded away from the footpath back to a concrete channel:</u> This layout will ensure that the overland flow path is not significantly impeded by the stormwater tree pit. Low flows can enter the stormwater tree pit via a single kerb opening on the concrete channel and high flows will bypass the stormwater tree pit when the capacity of the EDD area is exceeded. Refer Figure 8, Figure 10 and Figure 14.

- Stormwater tree pit constructed in the on-street parking bay with the kerb graded around the stormwater tree pit build-out: This layout will prevent the need to grade the on-street parking bay towards a concrete channel and ensure that overland flow paths are provided around the stormwater tree pit build-out. Refer Figure 7 and Figure 9.

- Stormwater tree pit constructed in the on-street parking bay with on-street parking bay grading to remain unchanged: Stormwater runoff will enter stormwater tree pit via a kerb opening on the upstream side of the stormwater tree pit. A kerb opening would also be provided on the downstream side of the stormwater tree pit to allow bypass of stormwater runoff exceeding the capacity of the ponding area. This configuration would result in the stormwater tree pit being constructed in the overland flow path. Therefore overland flow during larger storm events, such as the 2% AEP event, would need to pass through (upstream and downstream kerb opening) and around the stormwater tree pit. Refer Figure 11 and Figure 13.

- Stormwater tree pit constructed in isolated traffic island: This layout would allow the existing kerb alignment to be retained and used to capture low-flows as well as conveyance of flows in the 2% AEP event. Low-flow could be captured using a grade (or similar device) and diverted to the stormwater treatment device located in the isolated traffic island. Refer Figure 12.

Inlet Zone

It is important to deliver stormwater inflows so they are uniformly distributed over the entire surface and in a way that minimises flow velocity i.e. avoids scour and erosion, and maximises contact with the system for enhanced treatment. Therefore, distributed inflows are the preferred option; however this is not always possible (FAWB, 2009).

The small size of the street-scale stormwater tree pits typically ensures that stormwater is in contact with the entire system for enhanced treatment and to ensure all plants receive frequent passive irrigation to assist plant health.

At the point where inflows enter the stormwater tree pit (kerb opening), an area is needed for coarse sediments to accumulate (to avoid build-up and subsequent unintended diversion or flows around the system). This can be achieved by having a step down where the vegetation height is 40-50mm below the kerb opening invert in the inlet zone (FAWB, 2009). Note that vegetation in the inlet zone also needs to be dense to reduce flow velocities and protect against erosion.

The stormwater tree pit inlet control (kerb opening) controls the inflow rates into the system. When the stormwater tree pit is located off-line of the main overland flow path (i.e. within footpath), only low flows need to enter the stormwater tree pit, with high flows bypassed along the kerb and channel. In these cases the kerb opening only needs to be sized to allow flows up to the water quality volume to enter the stormwater tree pit. Alternatively when a stormwater tree pit is constructed within the on-street parking bay (on-line system), the kerb openings need to be sized to pass flows up to the 2% AEP event.

Outlet Zone

The outlet zone controls the volume of stormwater that can be captured and treated by the stormwater tree pit. Where possible, floods should be prevented from entering stormwater tree pits to prevent scour and erosion; however the feasibility of this will depend on site conditions (FAWB, 2009).

For the proposed stormwater tree pits, when the level of stormwater in the EDD area reaches the maximum extended detention depth, flows will bypass (around or through) the stormwater tree pit and enter stormwater sumps located further downstream.

Stormwater Kerb Outlets

All new stormwater laterals discharging clean roof or other treated stormwater should be provided with a direct connection to the existing CCC piped stormwater network. This provides a significant stormwater treatment outcome as it reduces the footprint of treatment devices in the street and ensures that these devices only treat the most polluted water.

Stormwater kerb outlets from existing developments should be replaced with direct connection stormwater laterals to the CCC piped stormwater network and on-site treatment provided where possible.

<u>Overland flow path capacity recommendation</u>

A key design consideration is ensuring that overland flow paths on roads have adequate capacity to convey and/or store flows beneath the finished floor level of adjacent developments during the 2% AEP event.

Designers must ensure that the pipe and kerb can convey the 20% AEP event beneath the top of kerb level and that the static 2% AEP event water level is not above adjacent finished floor levels, ideally with freeboard included.

Stormwater Tree Pit Stormwater Inlet and Flow Bypass

Stormwater tree pits can be incorporated into the kerb layout in numerous configurations. Some configurations that are likely to occur in the Christchurch CBD include:

- Stormwater tree pit constructed behind the kerb alignment: Stormwater runoff can enter the stormwater tree pit via a kerb opening and larger flows can bypass the device.
- Stormwater tree pit constructed in the on-street parking bay and on-street parking bay pavement regraded away from the footpath back to a concrete channel: Stormwater runoff can enter the stormwater tree pit via a kerb opening and larger flows can bypass the device within the concrete channel. This configuration requires careful detailing to prevent worsening flood impacts in traffic lanes and the on-street parking bay.
- Stormwater tree pit constructed in the on-street parking bay and kerb and channel graded around the stormwater tree pit build-out.
- Stormwater tree pit constructed in the on-street parking bay and on-street parking bay grading to remain unchanged: Stormwater runoff can enter the stormwater tree pit via a kerb opening on the upstream edge and larger flows can pass through the stormwater tree pit via a kerb opening on the downstream face. This configuration would result in the stormwater tree pit being constructed in the existing overland flow path along the kerb. Therefore overland flow during larger storm events, such as the 2% AEP event, would need to pass through and around the stormwater tree pit. This configuration therefore requires careful detailing to prevent worsening flood impacts in traffic lanes, the on-street parking bay and adjacent properties.

The dimensions of kerb openings should be sized to prevent flooding of adjacent properties, minimise inundation extents and prevent mulch and filter media from being damaged.

4.4.17 Sediment Load Management

A key consideration for the design of stormwater tree pits and rain gardens in post-earthquake Christchurch is construction sediment loads.

Protecting stormwater tree pits (and rain gardens) from large sediment loads will extend the design life of the treatment device, minimise the frequency in which maintenance is required, improve tree health and delay operational tasks such as rejuvenating the upper 100mm of filter media to reinstate the design infiltration capacity of the filter media.

Sediment Load Management recommendation

All new streetscape projects with stormwater tree pits and rain gardens included must consider construction stage sediment loads, future construction sediment loads from redevelopment sites adjacent the road corridor and facilitate a strategy to ensure the performance of stormwater treatment devices is not jeopardised.

Some potential design considerations include:

- Include a small sediment forebay within all stormwater tree pits and rain gardens. This could be either permanent or temporary until the completion of adjacent construction sites.
- Careful monitoring during construction of the streetscape project by the superintendent and ECan.
- When stormwater tree pits and rain gardens are combined, locate the kerb inlet away from stormwater tree pit.

Appropriate construction staging. The filter media for stormwater tree pits and rain gardens should not be installed until the road pavement and footpath has been established. A comprehensive erosion and sediment control plan must be developed.

5 LEVEL OF STORMWATER TREATMENT PROVIDED

5.1 80% CAPTURE OF STORMWATER VOLUME

The aim of this assessment is to determine the level of stormwater treatment that can be provided by a single stormwater tree pit constructed in the CBD in accordance with the design criteria recommendations presented in this report.

The level of stormwater treatment provided by the proposed stormwater tree pits has been assessed by calculating the percentage of stormwater runoff captured. An 80% capture of stormwater runoff volume is the benchmark for stormwater treatment in Christchurch.

The 30 minute interval continuous Botanical Gardens Rainfall record dating back to January 1963 (approximately 50 years of record) has been used to assess the percentage of stormwater runoff captured by each stormwater tree pit. More detail on the methodology used can be found in two earlier reports for the Avon SMP Blueprint; Rain Garden Criteria for Cost Effective Design (Christensen, 2013) and StormFilter Design Discharge Criterion (Parsons, 2013).

This analysis was undertaken for the following catchment area scenarios:

- Road and footpath only – comprising a 200m^2 catchment area (20m long by 10m wide). A 100% impervious ratio was assumed.
- Road, footpath and adjacent lot area – comprising a 1,200m^2 catchment area (20m by 10m road and footpath pavement section, 100% impervious) and (50m by 20m lot area, 90% impervious).
- Road and footpath only (length to achieve 80% stormwater capture) – trial and error assessment to determine what catchment area is required to achieve 80% capture of stormwater runoff from the road reserve only.

(NOTE: For the design of stormwater tree pits in actual CBD or suburban streets, the contributing impervious catchment area will need to be calculated to determine the spacing and final size of the devices.)

The percentage of stormwater runoff volume captured and pollutant removal efficiency have been investigated for stormwater tree pit optimal layout dimensions (3.5 x 3.5 x 1.5m soil volume and 3.5 x 2.3m ponding area). These dimensions could represent a stormwater tree pit located behind the kerb alignment or within the on-street parking bay (refer Figure 7 to Figure 12).

All of the stormwater tree pit layouts have a 150mm Extended Detention Depth (EDD).

The results from the analysis of the above three stormwater tree pits and contributing catchment area scenarios are discussed separately below.

5.1.1 Road and footpath only catchment

The road and footpath only catchment area has been estimated as approximately 200m^2. This catchment area would be expected to occur if stormwater tree pits were spaced every 20m along the kerb.

This scenario assumes that runoff from roofs and impervious surfaces on private lots discharges to existing piped stormwater infrastructure. Therefore the catchment area draining to each stormwater tree pit would only comprise the road and footpath pavement area. It was found that stormwater tree pits spaced at 20m (proposed by City Arborist for street trees) for the optimal tree pit dimensions will capture 92% of stormwater runoff volume. This percentage of stormwater capture exceeds the 80% volume capture requirement typically used to size stormwater treatments devices and therefore a greater level of stormwater treatment would be provided if stormwater tree pits were spaced at 20m spacing on both kerbs.

Stormwater tree pits could be spaced at a greater interval than every 20m and still achieve the desired 80% capture of stormwater runoff. This could be achieved by planting street trees at a greater spacing or potentially alternating stormwater tree pits and conventional tree pits along the road kerb.

5.1.2 Road, footpath and adjacent lot catchment

The road, footpath and adjacent contributing lot catchment area has been estimated as 1,200 m^2. This catchment area would be expected to occur if stormwater tree pits were spaced every 20m along the kerb and all stormwater runoff from adjacent lots (approximately 50m deep) was discharged directly to the kerb and channel.

This scenario resulted in a 40% capture of stormwater runoff volume which is less than the 80% capture requirement used to size rain gardens and stormwater tree pits using the NZTA procedure. Additional stormwater treatment measures may be required in the treatment train in these areas to ensure that the required stormwater quality improvement targets are achieved.

Ideally the kerb outlet would be replaced with direct connections to the piped stormwater network because this would reduce the catchment area contributing to treatment devices and also the total footprint of these treatment devices.

5.1.3 Catchment area to achieve 80% capture of stormwater

As discussed in Section 5.1.1, a 200m^2 catchment area contributing to a single stormwater tree pit (optimal tree pit dimensions) would result in capture of 92% of stormwater runoff. To reduce the volume captured to 80%, a maximum spacing of approximately 35m is required (assuming treatment of *only* the road reserve).

Potential configurations for stormwater tree pits are presented in Figure 23 (opposite spacing) and Figure 24 (alternate spacing) below. These both provide 80% stormwater runoff volume capture.

Figure 23 Stormwater Tree Pit Layout at 35m MAX Spacing (Opposite)

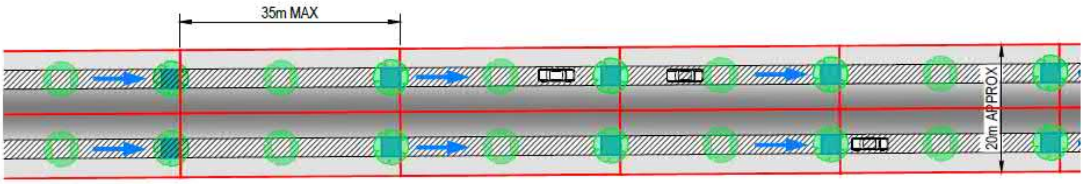
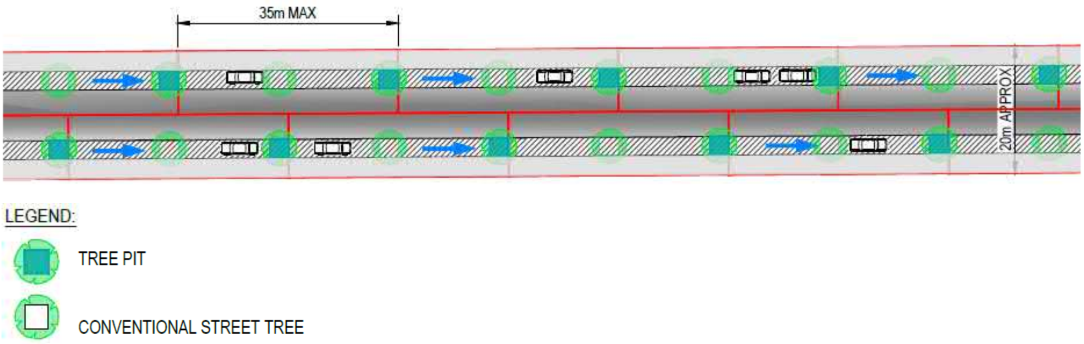


Figure 24 Stormwater Tree Pit Layout at 35m MAX Spacing (Alternate)



5.2 REDUCTION IN ANNUAL POLLUTANT LOAD

5.2.1 MUSIC Model

The MUSIC (Model for Urban Stormwater Improvement Conceptualisation) software developed by eWater is commonly used in Australia to plan and design appropriate urban stormwater management infrastructure for catchments.

MUSIC models stormwater runoff from catchments by converting rainfall into runoff and accounting for losses due to evapotranspiration, depression storage and soil storage. A long-term continuous rainfall time series is modelled in MUSIC. Pollutants are generated in MUSIC as rainfall is converted into stormwater runoff by attributing pollutant concentrations to stormwater runoff. Pollutant removal is then modelled in MUSIC for a range of stormwater management devices. MUSIC then presents the mean annual load for a range of pollutant types and estimates the proportion of pollutants removed by the selected stormwater treatment device i.e. stormwater tree pit. The removal efficiency of bioretention devices is based on the latest international research into the pollutant removal efficiency of bioretention devices.

MUSIC is mostly used to model Total Suspended Solid (TSS), Total Phosphorus (TP), Total Nitrogen and gross pollutants; however it can also be used to model heavy metals (i.e. Lead, Copper, Zinc and Cadmium) and hydrocarbons. Typical best practice Australian removal efficiencies are approximately 80-85% TSS, 45-70% TP and 45-60% TN. MUSIC is not commonly used to model heavy metals in Australia. There is currently suitable input data to estimate the mean annual load of heavy metal pollutants generated, but the removal efficiencies for heavy metals by bioretention devices has not currently been researched in enough detail for this to be included in MUSIC at this stage. For this reason this study has focused on TSS, TP and TN pollutant removal.

Pollutant generation in MUSIC is based on an analysis by Duncan, H.P. (1999) *Urban Stormwater Quality: A Statistical Overview, Report 99/3, Cooperative Research Centre for Catchment Hydrology* that found event mean pollutant concentrations (EMC) for TSS, TP and TN are approximately log-normally distributed. The default EMC values in MUSIC are based on a large international dataset of studies.

Whilst the MUSIC rainfall-runoff model has not yet been calibrated to local Christchurch rainfall data to determine suitable local pervious area soil losses; it can be applied to impervious catchments with local rainfall and evapotranspiration data.

MUSIC has been used to estimate the mean annual pollutant loads generated from the assumed stormwater tree pit catchment areas and to estimate the reduction in pollutant loads that can be expected to be achieved by each proposed stormwater tree pit. The 30 minute interval continuous Botanical Gardens Rainfall record dating back to January 1963 (approximately 50 years of record) and average monthly evapotranspiration data obtained from NIWA has been used in the MUSIC model for this assessment. 1mm depression storage has been adopted for impervious surfaces and default pollutant concentrations in MUSIC have been assumed. It is noted that the results from the MUSIC analysis should be considered preliminary until calibration of MUSIC to local Christchurch conditions has been undertaken. However, the pollutant loads are based on international studies similar to those cited in WWDG, and therefore if anything should be conservative (though this will vary on a catchment by catchment basis).

The pollutant removal efficiencies presented below are influenced by the selection of filter media infiltration rate. The filter media infiltration rate adopted corresponds with the value used in the rain garden design criterion report for consistency. It is noted that adopting a different infiltration rate will alter the pollutant removal efficiency and reduction in mean annual flow.

5.2.2 Estimated Reduction in Mean Annual Loads

Road Reserve only Contributing Catchment (20m stormwater tree pit spacing)

Table 4 presents the mean annual load and estimated reduction in annual load that can be achieved by each of the proposed stormwater tree pit layouts for the road reserve only contributing catchment (200m^2).

Table 4 Estimated Reduction in Mean Annual Loads for Road Reserve Catchment (20m stormwater tree pit spacing)

Pollutant	Mean Annual Load (kg/yr)	% Reduction in Load
Council optimal tree pit dimensions		
TSS	22.9	98.0
TP	0.1	83.6
TN	0.3	81.7

It can be seen from Table 4 that stormwater tree pits at 20m spacing and treating the road reserve only catchment are expected to capture a very high proportion of TSS, TP and TN.

It can also be seen from Table 4 that the mean annual load of TP and TN is about double what is recommended for a tree in low fertility soil (for both TN and TP). Consideration of these pollutant loads should be considered whilst determining fertiliser application rates.

The MUSIC model also estimates that the mean annual flow would be reduced by 44.8% for the optimal stormwater tree pit arrangement dimensions.

If the stormwater tree pit filter media depth is reduced from 1.5m to 1.0m as could occur in areas with a submerged zone installed, the reduction is pollutant load has been estimated as 97.9%, 82.0% and 80.8% for TSS, TP and TN respectively.

Road Reserve and Lot Contributing Catchment (20m stormwater tree pit spacing)

Table 5 presents the mean annual load and estimated reduction in annual load that can be achieved by each of the proposed stormwater tree pit layouts for the road reserve and lot contributing catchment (1,200m^2).

Table 5 Estimated Reduction in Mean Annual Loads for Road Reserve and Lot Catchment (20m stormwater tree pit spacing)

Pollutant	Mean Annual Load (kg/yr)	% Reduction in Load
Council optimal tree pit dimensions		
TSS	136.0	84.1
TP	0.3	63.2
TN	1.9	35.4

It can be seen from Table 5 that all the stormwater tree pit layouts are expected to capture a high percentage of the TSS (>75%) and TP. The percentage of TN captured is significantly less than that from the road reserve only catchment.

The MUSIC model also estimates that the mean annual flow would be reduced by 10.4% for the optimal stormwater tree pit arrangement dimensions.

If the stormwater tree pit filter media depth is reduced from 1.5m to 1.0m as could occur in areas with a submerged zone installed, the reduction is pollutant load has been estimated as 83.9%, 62.7% and 35.5% for TSS, TP and TN respectively.

Road Reserve only Contributing Catchment (35m stormwater tree pit spacing)

Table 6 presents the mean annual load and estimated reduction in annual load that can be achieved by each of the proposed stormwater tree pit layouts for the road reserve contributing catchment when stormwater tree pits are spaced at 35m intervals (350m^2).

Table 6 Estimated Reduction in Mean Annual Loads for Road Reserve Catchment (35m stormwater tree pit spacing)

Pollutant	Mean Annual Load (kg/yr)	% Reduction in Load
Council optimal tree pit dimensions		
TSS	39.7	95.4
TP	0.1	77.5
TN	0.6	68.4

It can be seen from Table 6 that stormwater tree pits at 35m spacing and treating the road reserve only catchment will capture a very high proportion of TSS, TP and TN.

The MUSIC model also estimates that the mean annual flow would be reduced by 29.7% for the optimal stormwater tree pit arrangement dimensions.

If the tree pit filter media depth is reduced from 1.5m to 1.0m as could occur in areas with a submerged zone installed, the reduction is pollutant load has been estimated as 95.4%, 76.5% and 68.1% for TSS, TP and TN respectively.

Summary of Results

The preliminary MUSIC analysis suggests that the proposed stormwater tree pit configuration will capture a large proportion of pollutants generated by stormwater runoff in the city.

It is noted that there are clearly differences between the CCC and MUSIC procedures for sizing stormwater tree pits. The CCC procedure focuses on capturing 80% of stormwater runoff volume (assumes adequate capture of stormwater pollutants) whilst the MUSIC procedure focuses on the load of pollutants captured by the stormwater tree pits.

The removal efficiency of heavy metals is influenced by the filter media specification (Read et al., 2008). Whilst heavy metals have not been modelled in MUSIC, it is noted that the high removal efficiency of TSS is expected to result in a high proportion of heavy metals removed by the proposed stormwater tree pits.

6 POTENTIAL INFRASTRUCTURE IMPACTS

Construction of stormwater tree pits within the CBD area needs to consider constraints such as infrastructure, vehicle movement, pedestrian movement etc. A preliminary assessment of some potential impacts associated with construction of stormwater tree pits is given in brief below:

- Loss of car parking – each stormwater tree pit would be expected to require one car parking bay for construction. However, the footprint required to construct a stormwater tree pit is similar to that of conventional tree pit.

- Building foundations – stormwater tree pit construction will not impact the design of foundations for adjacent buildings.

- Liquefaction – in-situ soils needs to be saturated for liquefaction to occur. Stormwater tree pits would be constructed with underdrains and a gravel drainage layer and therefore soils would only be saturated for short durations after storm events until the stormwater has passed through the filter media. The lower level of the stormwater tree pits may be frequently saturated in areas where submerged outlets are required for connection to existing piped stormwater infrastructure at higher elevations. Due to the small total area of saturated soils that would be created by the stormwater tree pits, it is unlikely that soils in the CBD would be exposed to a higher liquefaction risk.

- Damage to existing infrastructure and utility services – tree roots could damage existing utility services and infrastructure if not considered appropriately. Damage to surrounding infrastructure can be prevented by locating stormwater tree pits away from key infrastructure, ensuring minimum separations between stormwater tree pits and utility services is achieved where possible, installing root barriers and the careful selection of tree species to avoid large root structures that may spread and damage infrastructure.

- Infrastructure relocation – constructing stormwater tree pits in existing car parking areas could result in clashes with existing utility services and therefore service relocations is likely to be required. It is expected that shared services trenches (electricity, gas and telecommunications) will typically be located beneath footpaths, stormwater and sewer services will typically located beneath the main road pavement area and water mains will be located beneath car parking areas. Therefore it is possible that existing water mains and other infrastructure may need to be relocated around conventional tree pits and stormwater tree pits.

- Pedestrian safety – stormwater tree pits could result in a risk (trip/fall) to pedestrian movement if the EDD area was left open. This risk can be removed by constructing plant guards over stormwater tree pits at the existing surface elevation or by making them highly visible through dense planting.

7 PROPRIETARY PRODUCTS

There are some proprietary stormwater tree pit products commercially available within New Zealand. One example of these products is the Stormwater 360 Urban Green Biofilter. This product combines bioretention and media filtration in one system, with stormwater flows that exceed the capacity of the stormwater tree pit filter media bypassing into an adjacent Storm Filter. The stormwater tree pit dimensions are 1.65 x 1.65m by 0.9m deep. The City Arborist has identified that these dimensions are not considered appropriate to accommodate the proposed tree species in hard surface areas.

Proprietary stormwater tree pit devices could be used in the city however they are unlikely to have dimensions large enough for planting of the proposed tree species, and would be focused more on stormwater treatment outcomes than establishing healthy trees.

8 MAINTENANCE REQUIREMENTS

Stormwater tree pits require a number of maintenance activities be carried out to ensure the effective long-term function of the bioretention system and plant health is maintained.

8.1 TREE MAINTENANCE

The City Arborist identified the following tree maintenance requirements for stormwater tree pits.

Tree maintenance consists of:

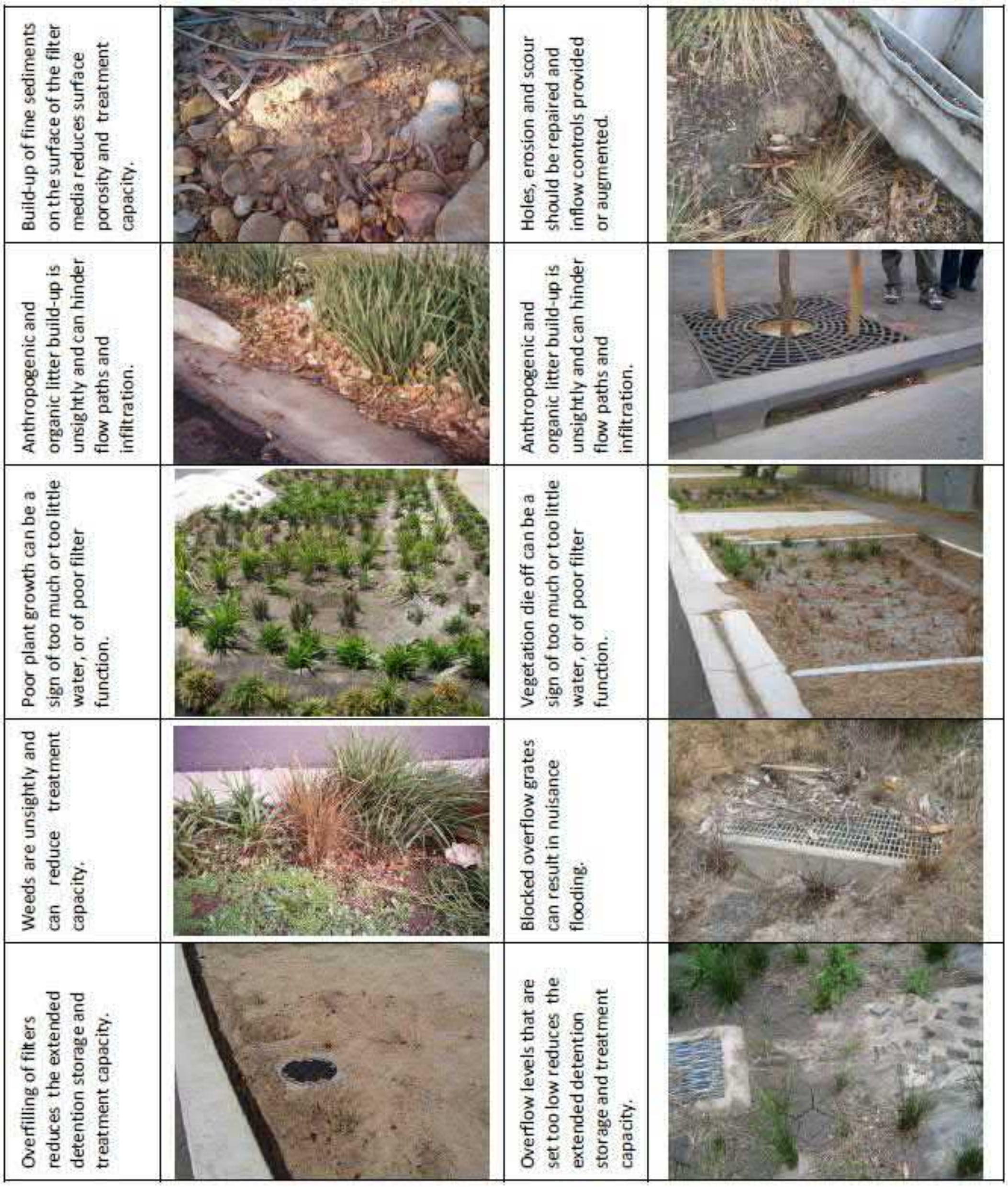
- ***Establishment Maintenance*** Ceases after the first 3 years after planting and consists of manual watering, formative/remedial pruning, adjusting stakes and ties, replacing damages stakes and ties, mulch replenishment and weed control.
- ***Planned Maintenance*** Commences after Establishment Maintenance ceases, undertaken on a cyclic basis (i.e. trees on arterial and collector roads are on an average 7 year maintenance cycle, trees on urban roads are on an average 10 year maintenance cycle). Planned maintenance includes activities such as overhead services clearance; removal of broken, dead or diseased branches, branches obstructing footpaths, cycle ways, carriageways, vehicle crossings, car parks; any other pruning required to maintain the health and structural integrity of the tree; emergency situations and formative pruning.
- ***Reactive Maintenance***
  Commences at planting and can involve any of the above maintenance activities throughout the life cycle of the tree.

8.2 GENERIC BIORETENTION DEVICE MAINTENANCE REQUIREMENTS

The FAWB (2009) guidelines outlines recommended inspection tasks, recommended frequencies and associated maintenance activities for bioretention devices such as stormwater tree pits and rain gardens. These tasks are presented in Figure 25.

Table 7 provides examples of maintenance issues presented in the FAWB (2009) guidelines.

<u>Figure 25 Example of Bioretention Issues Requiring Maintenance</u>



Source: FAWB (2009).

Table 7 Inspection and Maintenance Tasks for Bioretention Systems (Source: FAWB, 2009)

Inspection Task	Frequency	Comment	Maintenance Action
FILTER MEDIA			
Check for sediment deposition	3 monthly, after rain	Blocking of inlets and filter media reduces treatment capacity.	• Remove sediment from inlets, forebays and other pre-treatment measures, and the surface of Biofiltration street trees.
Check for holes, erosion and scour	3 monthly, after rain	Holes, erosion and scour can be a sign of excessive inflow velocities due to poor inflow control or inadequate provision for bypass of high flows.	• Infill and holes, repair erosion and scour • Provide/augment energy dissipation (e.g. rocks and pebbles at inlet). • Reconfigure inlet to bypass high flows. • Relocate inlet.
Inspect for build-up of oily or clayey sediment on the surface of the filter media	3 monthly, after rain	Reduced surface porosity reduces treatment capacity.	• Clear away and mulch on the surface and lightly rake over the surface of the filter media between plants.
Check for litter in and around treatment areas	3 monthly, after rain	Flow paths and infiltration through the filter media may be hindered.	• Remove both organic and anthropogenic litter.
HORTICULTURAL			
Assess plants for disease or pest infection	3 monthly, or as desired for aesthetics		• Treat or replace as necessary.
Check plants for signs of stunted growth or die off.	3 monthly, or as desired for aesthetics	Poor health can be a sign of too much or too little water, or poor flow control.	• Check inlet and overflow levels are correct and reset as required. For too much water: • Replace plants with species more tolerant of wet conditions. OR • Replace filter media with that of a higher infiltration capacity. For too little water: • Consider installing a choke on the outlet OR • Replant with species more tolerant of dry conditions.
Check that original plant densities are maintained	3 monthly, or as desired for aesthetics	Plants are essential for pollutant removal and maintaining drainage capacity. Plants should be close enough that their roots touch each other; 6-10 plants /m^2 is generally adequate. A high plant density also helps prevent ingress of weeds.	• Carry out infill planting as required – plants should be evenly spaced to help prevent scouring due to a concentration of flow.

Inspection Task	Frequency	Comment	Maintenance Action
Check for presence of weeds	3 monthly, or as desired for aesthetics	Weeds can reduce aesthetics and treatment capacity because some plants are more effective at pollutant removal than others.	• Manually remove weeds where possible – where this is not feasible, spot spray weeds with a herbicide appropriate for use near waterways.
DRAINAGE			
Check that underdrain is not blocked with sediment or roots	6 monthly, after rain	Filter media and plants can become waterlogged if the underdrain is chocked or blocked. Remove camera (CCTV) inspection of pipelines could be useful.	• Clear underdrain as required using a pipe snake or water jet. • Water jets should be used with care in perforated pipes.
Check that the water level in the submerged zone (if applicable) is at the design level.	6 monthly, after rain	Drawdown during dry periods is expected.	• Check outflow level is correct and reset as required.
Check that inflow areas, weirs and grates over pits are clear of litter and debris and in good and safe condition.	Monthly, and occasionally after rain	A blocked grate or inlet would cause nuisance flooding.	• Replace dislodged or damaged pit covers as required. • Remove sediment from pits and entry sites (likely to be an irregular occurrence in mature catchments).
OTHER			
Observe Biofiltration system after a rainfall event to check drainage.	Twice a year, after rain	Ponding on the filter media surface for more than a few hours after rain is a sign of poor drainage.	• Check catchment land use and assess whether it has altered from design capacity (e.g. unusually high sediment loads may require installation of a sediment forebay).

It is acknowledged that not all of the inspection and maintenance tasks listed in Table 7 may be applicable to the proposed stormwater tree pits in the city however; the stormwater tree pit design is likely to differ for different areas in the city and therefore the information presented above may be applicable.

Christchurch City Council has facilitated internal meetings to discuss maintenance concerns for stormwater tree pits with operations and maintenance staff within Council. The minutes from this meeting are included in Appendix A. All designs must carefully consider these maintenance concerns.

Auckland Council has developed a rain garden operation and maintenance brochure which covers both the function and maintenance of rain gardens and could be a model for CCC to follow. It can be found at: http://www.wsud.org/wp-content/uploads/2012/08/Raingardens-Operaton-Maintenance-Guide_0.pdf

Table 8 Auckland Council Rain Garden Operation and Maintenance Guidelines

Following Storms	
Grass filter strip (if included), kerbing, paved area	• Remove rubbish, leaves and other debris from the grass filter strip and surrounding drainage area.
Ponding area	• Clear inflow points of sediment, rubbish and leaves. • Check for erosion or gouging and repair. • Test drainage of ponding area - check garden 24 hours after rain to ensure no water is ponding. • Top up soil and mulch as necessary (ensuring level is below surrounding hard surface and overflow).
Mulch	• Mulch may need to be redistributed or added around inflow points.
Three Monthly	
Grass filter strip, kerbing, paved area	• If grass strip is present, mowing frequency depends on growth rates and seasons. • Mow no shorter than 50mm (approximately 3 finger widths). Do not mow grass shorter or the filter strip will not work properly. • Re-sow grass as necessary. • Remove rubbish, leaves and other debris. • Check soil and mulch level is below surrounding hard surface areas and overflow. • Remove excess mulch/soil if required.
Ponding area	• Clear inflow points of built up sediment, rubbish and leaves. Check for erosion or gouging – repair if necessary.
Mulch layer (bark, pebbles, etc.)	• Remove rubbish, leaves and other debris. • After storm events mulch may need to be redistributed or added around inflow points.
Plants	• Water establishing plants monthly during extended dry periods. • Check plant health and replace dead plants as necessary. • Use native species to suit garden conditions (e.g. full sun or shaded). - See ARC TP10 for partial list of suitable species. • Remove weeds – do not use herbicides, pesticides

Annual Maintenance	
Ponding area	• Clear inflow points of sediment, rubbish and leaves. • Check for erosion or gouging and repair. • Check all water has drained 24 hours after heavy rain. • Alternatively test drainage of ponding area. Dig a hole 200mm wide x 200mm deep. Pour in 10 litres water in hole. Check drainage rate over 1 hour period - minimum 25mm/hour. • If crust of fine sediment present on surface of soil mix, remove with spade and rework using rake. Top up soil and mulch as necessary (ensuring level is below surrounding hard surface and overflow). Dispose of contaminated crusted topsoil in a secure landfill (unless soil testing shows no contamination).
Rain garden soil mix	• Check soil level is below surrounding hard surface level and overflow grate. Use drainage test described above to check soil is free draining.
Mulch layer (bark, pebbles, etc.)	• Check surface of mulch for build-up of sediment, remove and replace as required.
Underdrain system	• Use inspection well (if present) to check underdrain is working properly. • Check rain garden draining freely using the drainage test. If rain garden is not free-draining, the underdrain may be blocked. Try back-washing under drain from the outlet. If still blocked, the rain garden may need plants and rain garden soil mix removed and replaced.

8.3 UNDERDRAIN CONSIDERATIONS

The potential for tree roots to enter the underdrain pipes can be minimised by numerous factors such as:

- Using a submerged zone within the stormwater tree pit. Tree roots will grow down and generally stop at the water level of the submerged zone provided appropriate tree species are selected.
- Providing an adequate tree pit footprint to ensure tree roots can grow outwards, rather than downwards (achieved by the optimal stormwater tree pit dimensions).
- Appropriate tree species selection to prevent tree roots growing into the saturated zone layer.
- Using a 225mm diameter sacrificial riser for the stand pipe will provide an additional level of protection against blockage. After root intrusion, replace internal removable 100mm diameter sacrificial riser and flange (or rubber ring) using a hand auger. Refer Figure 15.
- Using slotted PVC underdrains.
- Lack of nutrients, fines and oxygen in the lower transition layer and saturated zone layer soils to discourage roots in this area.

The provision of a standpipe (flushing point) in each stormwater tree pit will allow inspection and maintenance of the underdrains i.e. flushing or rodding of the underdrain in the event of blockage.

The published design life of a PVC pipe is typically between 50 and 100 years. It is expected that the design life of the underdrain pipe will equivalent to the design life of the proposed trees within the CBD. The use of sacrificial stand pipes will allow the riser to be replaced if it is blocked or damaged during the design life of the tree.

It is noted that given most stormwater tree pits will have a submerged zone (due to the shallow depth of existing stormwater infrastructure in the city to receive the treated flows); underdrains are not expected to be required in stormwater tree pits. Also locating the standpipe near the edge of the stormwater tree pits will allow future replacement without damaging the established trees within the stormwater tree pits.

8.4 MAINTAINING POROSITY OF FILTER MEDIA

Rain garden plants typically have active root growth and die-back and this provides capillary voids to help maintain porosity of media. The smaller roots in the tree root ball will grow and die off and this creates pores in the media, similar to rain gardens, provided adequate tree species are selected. Planting rain-garden style vegetation as well as tree will further improve this mechanism.

The City of Melbourne Council uses tree covers rather than rain-garden planting in stormwater tree pits and they currently have not identified any devices that are not functioning as a result of reduced infiltration rates in media. These devices have been in place for up to seven years. Stormwater tree pits in Christchurch are expected to typically comprise rain garden plants and this will therefore assist in maintaining the porosity of filter media.

8.5 REJUVENATION OF FILTER MEDIA

The design intent is to only replace the top layer of media if infiltration capacity is reduced. The full media depth is not expected to be replaced. Some trees don't like the removal of the top layer so need to carefully consider tree species selection. The upper 100mm is at most risk of clogging from sediment.

It is not proposed that trees be removed from stormwater tree pits. Even if the media infiltration rate is reduced, they will still provide passive irrigation and hence urban amenity outcomes.

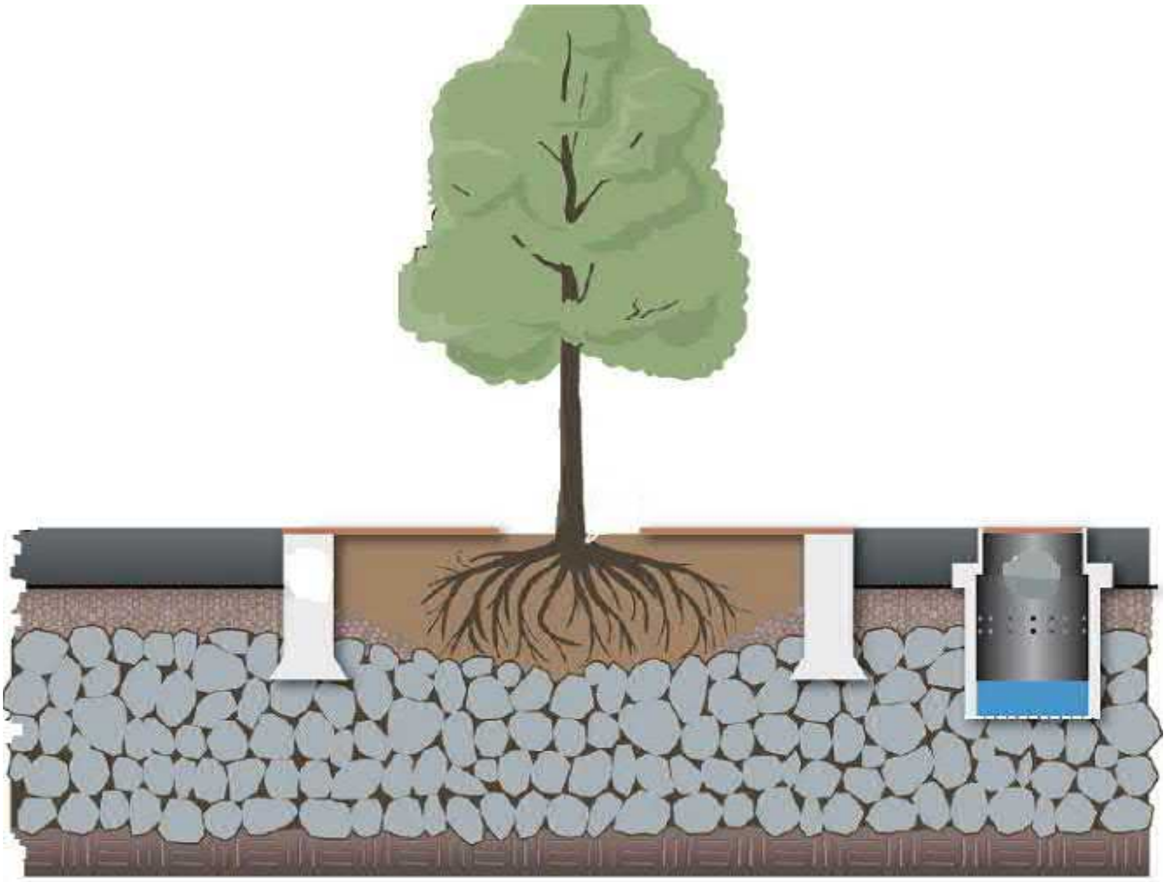
The City of Melbourne Council and Auckland Transport have advised that their operational/maintenance intent for stormwater tree pits is to only replace the upper 100mm layer. Neither has had to do this yet for stormwater tree pits.

This is less of an issue for combined stormwater tree pits and rain gardens, as for these devices the rain garden filter media can be separated from the tree pit soil media by an internal barrier such as a root barrier or retaining wall. This would allow the full depth of filter media in the rain garden to be replaced without impacting the established tree in the adjacent tree pit.

If the infiltration capacity of the filter media is reduced below 20mm/hr and filter media porosity cannot be improved from further rejuvenation, stormwater could begin ponding in the bioretention device for extended periods. The design life of the stormwater treatment device could potentially be extended by modifying the stormwater tree pit to facilitate stormwater to enter the underdrain from the piped stormwater network. This stormwater could be stored within the lower layers of the bioretention device and used for uptake by the tree and infiltration to the in-situ soil media. This modification could be easily made for stormwater tree pits located adjacent stormwater sumps by installing a submerged outlet within the sump (to allow stormwater to enter the underdrain from the piped network) and filling the EDD storage area with gravel (to minimise the trip hazard and prevent stormwater ponding in the EDD area).

The above potential design modification is based on a solution commonly used in Stockholm and throughout Europe to improve tree health and local stormwater management that incorporates a gravel storage bed beneath tree pits for tree uptake and infiltration to groundwater. A schematic of this stormwater management solution is presented in Figure 26.

Figure 26 Stormwater Storage beneath Clustered Tree Pit Typical Configuration



Source: The Stockholm Solution – Ten Years of Experience of Urban Tree Planting and Management Combined with Local Stormwater Management, City of Stockholm Traffic Administration

9 COST ESTIMATES

9.1 CAPITAL COST

A preliminary cost estimate has been undertaken for construction of stormwater tree pits in the city. The CAPEX for the three stormwater tree pit layouts presented in this study is summarised in Table 9. The incremental cost of constructing a stormwater tree pit over a conventional tree pit is also presented in Table 9.

Table 9 Capital Costs

Stormwater Tree Pit Layout	CAPEX Cost (excl GST)	Incremental CAPEX over standard Tree Pit (excl GST)
Optimal tree pit dimensions	$9,400	$1,800

The above CAPEX cost estimates are based on the following assumptions:

- The stormwater tree pits will be constructed as part of the street renewal works and therefore site establishment, site clearance, traffic management, road reconstruction (including pervious pavement), as-built plans and quality assurance costs can be excluded from the stormwater tree pit cost estimates as they will be covered by the street renewal works.
- All stormwater tree pits will be in Council road reserves and therefore land acquisition costs are not required.
- No consenting fees are required because stormwater tree pit construction would be covered by the Avon SMP or SCIRT Street renewal works.
- Stormwater tree pit comprises a single central tree surrounded by rain garden plantings. Hence no tree cover has been included.
- No utility service relocations are required.
- An existing stormwater pipe is located in the street to receive treated stormwater runoff from the stormwater tree pit via underdrain.
- Professional fees assumed to be 14% of construction costs and a 25% contingency included.
- No dewatering is required during construction.

It is noted that the construction of stormwater tree pits will require existing services to be relocated in some locations. Also some streets will not have an existing stormwater pipe to accept treated stormwater discharge, requiring construction of a stormwater pipe before road reconstruction. These items will differ between different streets in the city and additional costs will be required.

Inclusion of additional design elements such as a tree cover would also increase the CAPEX of each stormwater tree pit layout.

9.2 ANNUAL COST REQUIREMENTS

Annual costs for maintenance of stormwater tree pits are presented below (for a tree pit catchment of 400m²). The costs are based on those presented for rain gardens in the Landcare Research Costnz costing model. The costs assume that maintenance takes place on a series of tree pits in one area to reduce costs. The costs will vary based on the type of cover (vegetation or mulch) in each of the tree pits.

Table 10 OPEX Costs

Item	Unit	Frequency / year	Rate	Annual Cost
Routine landscape maintenance (removing litter, maintaining vegetation, weeding)	per tree pit	12	$10	$120
Routine drainage maintenance (removing sediment, clearing inlets and outlets)	per tree pit	4	$25	$100
Inspections of outlets and integrity of biofilter	per tree pit	1	$50	$50
TOTAL				**$270**

Less regular maintenance tasks are removal and replacement of the top 100mm of filter media (including mulch and plants) every 10 years, and replacement of the sacrificial riser (if installed) and other minor drainage parts every 10 years. These costs have been estimated as $1,750 every 10 years (including 15% establishment allowance), or $175 per year (not adjusted for net present value).

This gives a total annual cost of $445 per year per tree pit. It is estimated that this cost has an accuracy of +50%/-25%. Note that the cost of the stormwater component only (ignoring landscaping) is approximately half of that figure. Costs of maintenance are likely to be shared between streetscape and stormwater budgets. Costs of maintenance are likely to be shared between streetscape and stormwater budgets.

10 CONCLUSIONS

This study has presented an optimised design of stormwater tree pits for use in the Christchurch CBD and the Avon SMP Blueprint. Stormwater tree pits are considered suitable for stormwater treatment in the Christchurch CBD and suburban catchments due to existing plans to increase the number of street trees, the level of stormwater treatment achieved, the ability to be combined with conventional tree pit planting, the ability to provide passive irrigation of street trees, and also provide multi-value benefits such as street amenity and habitat creation consistent with the Surface Water Management Strategy.

11 ACKNOWLEDGEMENTS

The valuable contributions made by Shane Moohan, City Arborist to this report are acknowledged. Workshops were also held to obtain feedback on the initial designs, and the participation of many Council staff in these is gratefully acknowledged. Peter Wehrmann's contribution is particularly acknowledged.

12 REFERENCES

Bratieres, K., Fletcher, T.D., Deletic, A., and Zinger, Y. (2008). Nutrient and sediment removal by stormwater biofilters; a large-scale design optimisation study. Water Res., 42, 3939-3940.

CCC (2003), *Waterways, Wetlands and Drainage Guide*, Christchurch City Council.

CERA (2013). *An Accessible City – Christchurch Central Recovery Plan: Replacement transport chapter – October 2013.* Christchurch: Canterbury Earthquake Recovery Authority.

City of Melbourne Council (2013). Eades Place & Stanley Street, Street Scape Works Design Drawings.

Christensen, P, (2013). Rain Garden Criteria for Cost Effective Design, Prepared by the Capital Programme Group, Christchurch City Council.

Clearwater (2012), Tree Pit Design Principles Quick Reference Guide.

Davis, A.P., Shokouhian, M., Sharma, H., and Minami, C. 2006. Water quality improvement through bioretention media: Nitrogen and phosphorus removal. Water Environ. Res., 78, 284-293.

Denman, L. (2006). Are Street Trees and their Soils an Effective Stormwater Treatment Measure? The 7th National Street Tree Symposium, 2006.

Duncan, Hugh P. (1999). Urban Stormwater Quality: A Statistical Overview. Cooperative Research Centre for Catchment Hydrology., 134.

eWater (2012). MUSIC by eWater User Manual.

Fassman, EA, Simcock, R, Wang, S, (2013). *Media specification for stormwater rain gardens, Prepared by Auckland UniServices for Auckland Council*. Auckland Council technical report, TR2013/011.

FAWB (2009). Guidelines for Filter Media in Biofiltration Systems (Version 3.01) (pp. 1-8). Facility for Advanced Water Biofiltration Retrieved from http://www.monash.edu.au/fawb/products/obtain.html. accessed 2013.

Hatt, B.E., Deletic, A., and Fletcher, T.D. 2007. Stormwater reuse: designing Biofiltration systems for reliable treatment. Water Sci. Technol., 55, 201-209.

Hsieh, C.H. and Davis, A.P. 2005. Evaluation and optimisation of bioretention media for treatment of urban stormwater runoff. J. Environ. Eng.-Asce, 131, 1521-1531.

Hunt, W. and W. Lord. 2006. “Rain garden Performance, Design, Construction, and Maintenance.” North Carolina Cooperative Extension Service Bulletin.

Le Coustumer, S., Fletcher, T.D., Deletic, A., and Barraud, S. 2007. Hydraulic performance of biofilters: first lessons from both laboratory and field studies. Water Sci. Technol., 56,93-100.

NZTA (2010) *Stormwater Treatment for State Highway Infrastructure,* New Zealand Transport Agency

NZTA (2010). *Stormwater Treatment for Road Infrastructure*, New Zealand Transport Agency.

Parsons (2013). StormFilter Design Discharge Criterion Report.

Somes, N. and J. Crosby (2007). “Review of Street Scale WSUD in Melbourne: Study Findings.” Kingston City Council and the Better Bays and Waterways Institutionalising Water Sensitive Urban Design and Best Management Practice Project.

Read, Jennifer, Fletcher, Tim D., Wevill, Tricia and Deletic, Ana (2010) ‘Plant Traits that Enhance Pollutant Removal from Stormwater in Biofiltration Systems’, International Journal of Phytoremediation, 12: 1,34-53, First published on: 01 January 2010 (iFirst).

Sun, X. and Davis, A.P. 2007. Heavy metal fates in laboratory bioretention systems. Chemosphere, 66, 1601-1609.

Tonkin & Taylor (2012). Assessment of Median Shallow Groundwater Surface for Christchurch and Surrounding Areas.

Zinger, Y., Fletcher, T.D., Deletic, A., Blecken, G.T., and Viklander, M. 2007. Optimisation of the nitrogen retention capacity of stormwater Biofiltration systems. Paper presented at the Novatech, Lyon, France, June 24-28, 2007.

APPENDIX A

Christchurch City Council Maintenance Meeting Minutes

Christchurch City Council

Capital Investigations

NOTES FROM MEETING

SUBJECT: **STORMWATER TREE PITS – MAINTENANCE ISSUES**

DATE: 25 JUNE 2014

PRESENT:
* Facilitator

Ken Couling*
Owen Southen
Dennis Preston
Peter Wehrmann
Dave Pinkney
Peter Christensen (Aurecon)
Mark Stone (Aurecon)

	ISSUE:	COMMENT /ACTION :
1	Trees may need to be removed every 20 years to refurbish the tree pit. It will be difficult to scrape away the top 100mm because of dense fibrous roots around the bole of the tree. The design intent is to only replace the top layer of media if infiltration capacity is reduced. The full media depth is not expected to be replaced. Some trees don't like the removal of the top layer so need to carefully consider tree species selection. The upper 100mm is at most risk of clogging from sediment. It is not proposed that trees be removed from stormwater tree pits. Even if the media infiltration rate is reduced, they will still provide passive irrigation and hence urban amenity outcomes. The City of Melbourne Council and Auckland Transport advised that their operational/maintenance intent for stormwater tree pits is to only replace the upper 100mm layer. Neither has had to do this yet for stormwater tree pits.	Most contamination is likely to be in the top 100mm (Mark will check out Melbourne and Auckland experience).

	ISSUE:	COMMENT /ACTION :
2	Roots are likely to penetrate the subsoil pipes. The City of Melbourne Council and Auckland Transport are not concerned with this issue as they feel their designs address this potential of this. They have not had any issues with blockage of underdrains in stormwater tree pits. Underdrain blockage can be managed by the use of submerged zones as tree roots typically grow down and generally stop at the water level of the submerged zone, provided adequate tree species are selected. Other engineered solutions exist such as adequate underdrain specification. The engineered solutions provide an additional level of protection. Also adopting a sacrificial riser provides an additional level of protection against blockage. For the An Accessible City projects it is proposed to provide several levels of protection against tree root blockage in underdrains. This will be addressed using submerged zones, engineered strategies and sacrificial standpipes.	Peter has designed a sacrificial vertical pipe.
3	Not all CBD sites/streets are suitable for tree pits because of service clashes. There will be a mixture of rain gardens and tree pits. Yes. We are likely to find that rain gardens are best in some locations and stormwater tree pits in others. Using a combination of the above treatment devices for contingency in the stormwater treatment strategy is ideal.	Hospital corner, Cambridge/Durham unsuitable. Manchester 70% tree pits.
4	Soil media will consolidate/compact over time. Rain garden plants typically have active root growth and die-back and this provides capillary voids to help maintain porosity of media. The smaller roots in the tree root ball will grow and die off and this creates pores in the media, similar to rain gardens, provided adequate tree species are selected. Planting rain-garden style vegetation as well as tree will further improve this mechanism. The City of Melbourne Council uses tree covers rather than rain-garden planting in stormwater tree pits and they currently have not identified any devices that are not functioning as a result of reduced infiltration rates in media. These devices have been in place for up to seven years.	Tree roots will delay compaction (Mark will check out Melbourne and Auckland experience).

	ISSUE:	COMMENT /ACTION :
5	Street sweeper will find it difficult to manoeuvre around build-outs. Noted. The design of build-outs can consider this to try and prevent as far as possible corners that rely on sweeping by broom only.	A person with a broom already accompanies the sweeper in the CBD.
6	How will sand be prevented from migrating into the drainage layer? The grading of material in the filter media layer, transition layer and drainage layers are selected to prevent migration of fines into the underlying layers. The purpose of the transition layer is to prevent material in the filter media layer migrating into the drainage layer. The grading of the drainage layer is specified to prevent migration of material from the transition layer into the drainage layer.	We need to rely on appropriate soil grading (Mark will check out Melbourne and Auckland experience).
7	A high frequency of maintenance will be required to maintain public support for tree pits. The City of Melbourne Council have advised that stormwater tree pits have a significant benefit on urban amenity and that trees planted in stormwater tree pits are healthier than others in the city. They have advised that litter entering devices needs to be routinely removed but it is difficult to collect sediment and not litter. Adequate maintenance is the most important consideration for all bioretention devices. Failure of stormwater tree pits have occurred due to sediment accumulating on the surface and therefore preventing water reaching the tree roots. The same issue applies for rain gardens. Temporary measures could be incorporated into rain gardens and tree pits to facilitate the removal of sediment and litter during the rebuilt of Christchurch. These could be removed at a later stage when surrounding catchment areas are established.	It may be beneficial for rubbish to be visible on tree pits.
8	What about ‘passive’ tree pits located below kerb or surrounded by permeable pavement (e.g. Nelson)? Tree pits designed with passive irrigation have many urban amenity benefits. They will also reduce the sediment load entering rain gardens and stormwater tree pits located downstream of them. No underdrains would be included in these tree pits so adequate tree species selection is required. The ponding depth only needs to be small. Permeable pavement is used around some stormwater tree pits in Melbourne, Auckland and other areas however it is	Soils in the CBD have low infiltration rates. Roots could be saturated for a long time.

	ISSUE:	COMMENT /ACTION :
	not currently being maintained due to a lack of suitable equipment. The high risk of clogging in Christchurch is likely to make the use of permeable pavement undesirable in the short-term.	
9	Submerged tree pits may not meet IDS requirements on road subgrade and standing water. Stormwater tree pits constructed adjacent road pavements may require a retaining wall to prevent water entering pavement subgrade. This detail is yet to be confirmed. Where possible they will be located behind the kerb with a batter to prevent the need for a retaining wall and water entering the pavement subgrade. Auckland and Melbourne are constructing stormwater tree pits in on-street parking bays.	
10	The tree pit timber or concrete edge is likely to need strengthening. Structural soil may not support edge. Stormwater tree pits constructed adjacent road pavements may require a concrete retaining wall on the edge. Alternatively the entire tree pit could be filled with a structural soil media so prevent compaction of media by adjacent traffic loads. Lime stabilised media will likely reduce the infiltration capacity and prevent devices functioning adequately.	Can structural soil be lime stabilised? A vertical wall was used at Addington (Mark will check out Melbourne and Auckland experience).
11	<u>Rain gardens</u> Considered more manageable with more predictable maintenance outcomes. Rain gardens and stormwater tree pits are both bioretention devices with the same maintenance requirements. Stormwater tree pits have not been used for as long as rain gardens but many jurisdictions use and promote their use.	It should be relatively easy to replace plants.
12	It needs to be resolved whether rain gardens and tree pits are to be managed as a street landscape or drainage asset. Acknowledged CCC will need to clarify. Maintenance of these devices in Auckland is being undertaken by Auckland Council whose responsibility it is to maintain drainage infrastructure. Street sweeping is being undertaken by Auckland Transport.	Owen would prefer they were managed as a drainage asset.