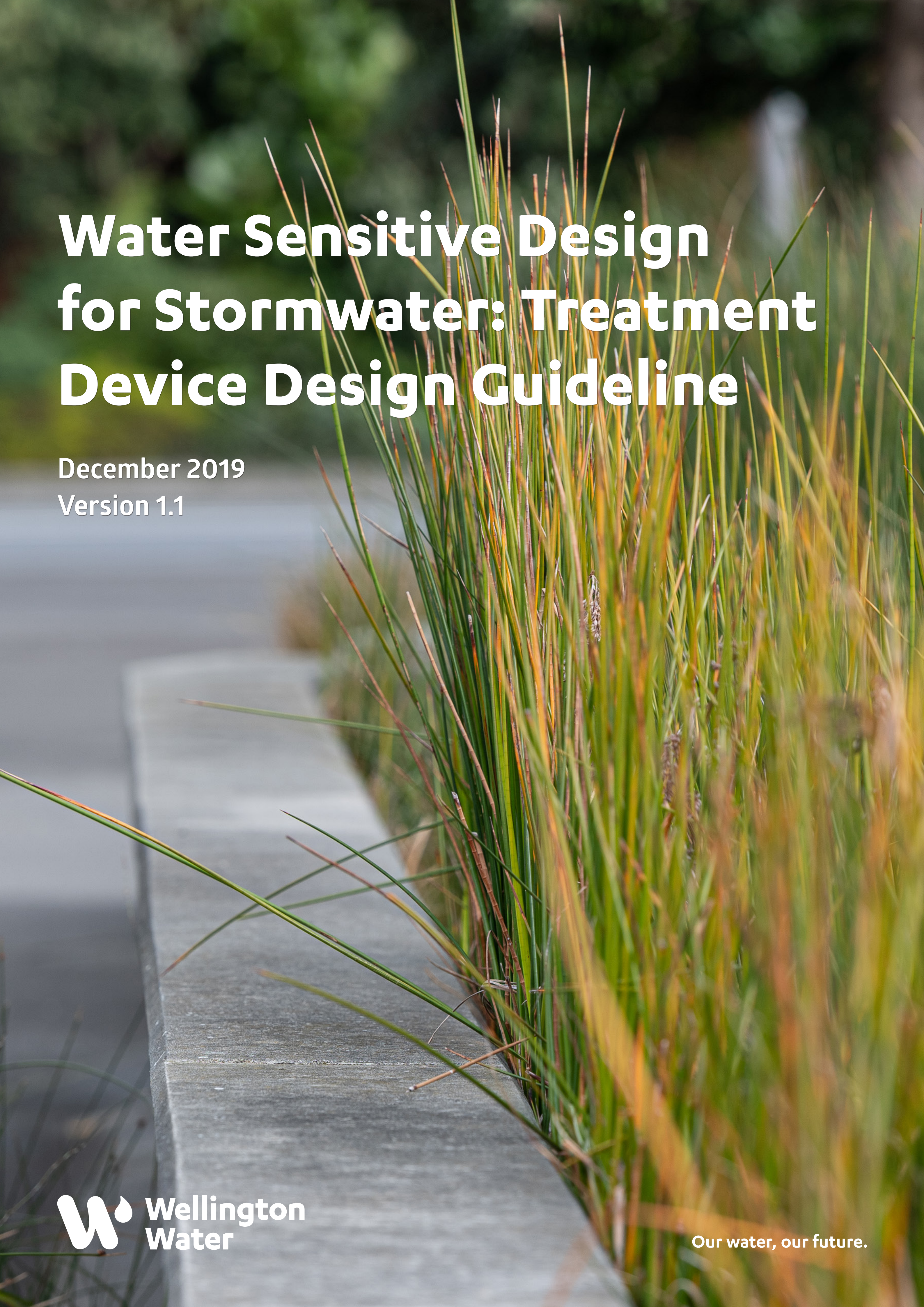

Water Sensitive Design for Stormwater: Treatment Device Design Guideline

December 2019
Version 1.1

Wellington Water

Our water, our future.

Water Sensitive Design for Stormwater: Treatment Device Design Guideline

Version No.	Version Description	Date
1.1	Minor update for corrections	18 December 2019
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Cover image: Subsurface constructed wetland at Waitangi Park, Wellington. Constructed in 2005, Waitangi Park is a stormwater treatment system that is thoughtfully integrated into the Chaffers Wharf precinct. Waitangi Park is a good example of water sensitive design in the Wellington region

HOW TO USE THIS GUIDELINE

The diagram below shows the recommended design process and associated guidance for each step.

Design process step	Recommended guidance

FULL GUIDANCE UNDER DEVELOPMENT

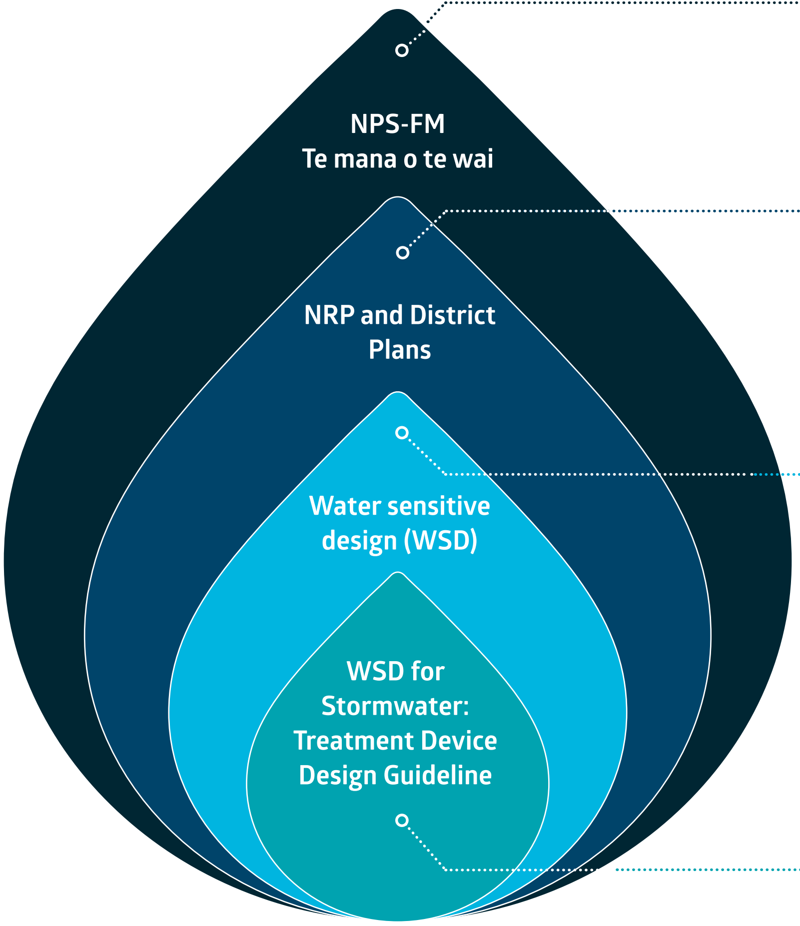
Design process step	Recommended guidance
Project scoping	In consultation with Land Development Team at Wellington Water
Site assessment	Sections A to D of Water Sensitive Design for Stormwater (GD04)
Define mitigation requirements	Section 2.1, District Plans, and the Natural Resources Plan for the Wellington Region

FULL GUIDANCE AVAILABLE

Design process step	Recommended guidance
Identify treatment options	Section 2.2 Concept design, 2.3 Treatment options, and sections 3 to 6
Size treatment options	Section 2.4 Technical design and sizing, and sections 3 to 6
Life cycle cost analysis	Section 2.5 Life cycle costs
Refine through design development	Section 2.6 Design development

FRAMEWORK FOR IMPROVING WATER QUALITY

The diagram below shows how this guideline fits into the national framework for improving water quality.



National Policy Statement for Freshwater Management (NPS-FM) recognises te mana o te wai (the integrated and holistic well-being of water) and sets out objectives and policies that direct local government to manage water in an integrated and sustainable way, while providing for economic growth within set water quantity and quality limits.

Regional councils must give effect to the national objectives set by the NPS-FM at a regional level in the Natural Resources Plan and integrate the recommendations made by community-led groups known as whaitua.

In turn, district and city councils must set planning objectives and rules for new development and associated three waters infrastructure that support the Natural Resources Plan.

Water sensitive design (WSD) is a best practice approach for the management of stormwater to reduce run-off volume and contamination

WSD encompasses a wide range of activities, including but not limited to:

- source control
- urban design
- water re-use
- green infrastructure
- run-off volume reduction.

Water Sensitive Design for Stormwater: Treatment Device Design Guideline is a best practice guideline for the design of four types of stormwater treatment devices to reduce stormwater contamination.

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Constructed wetland at Waitangi Park, Wellington. The functional design of Waitangi Park is focused on sustainability. Constructed wetlands are used to treat stormwater contamination and an open pond (out of picture) allows the re-use of the stormwater for irrigation of nearby greenspaces.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
AEP	Annual exceedance probability
CMC	Corrective maintenance costs
DC	Decommissioning costs
DR	Discount rate
EDD	Event detention depth
EDL	Event detention level
EDV	Event detention volume
FSV	Flood storage volume
FWL	Flood water level
GCL	Geosynthetic clay liner
GIS	Geospatial information system
GPT	Gross pollutant trap
GWRC	Greater Wellington Regional Council
HRT	Hydraulic retention time
IWS	Internal water storage
LCAP	Life cycle analysis period
LCC	Life cycle costing
LS	Life span
NPV	Net Present Value
NZTA	New Zealand Transport Agency
OLFP	Overland flow path
PSD	Particle size distribution
PWL	Permanent water level
PWV	Permanent water volume
RMC	Routine maintenance costs
TAC	Total acquisition cost
VPD	Vehicles per day
WQF	Water quality flowrate
WQV	Water quality volume
WSD	Water sensitive design

LIST OF DEFINITIONS

Term	Definition
Annual exceedance probability	The probability of a rain event happening in any one year, typically expressed as a percentage (10%) as opposed to a ratio (1 in 10 years).
Corrective maintenance costs	Costs associated with large scale maintenance of the treatment device. They occur infrequently over the life of a device.
Decommissioning costs	Costs associated with the decommissioning or complete removal of the treatment device at the end of its life span.
Discount rate	A percentage rate used to discount the costs back to their present-day value. Discounting is used to find the value at the base year of future costs, in other words, the NPV.
Event detention	Event detention allows for the temporary attenuation of stormwater runoff above the PWL (wetland) or filter surface (bioretention) to support the effective treatment within devices and providing protection of downstream waterways through reducing peak runoff flowrates.
Event detention depth	The depth of the event detention volume (EDV) above the permanent water level (PWL).
Event detention level	The maximum height reached by the event detention volume (EDV)
Event detention volume	Event detention volume (EDV) is the volume allowed for event detention.
Forebay	The wetland forebay provides coarse sediment removal prior to runoff entering the main wetland body.
Flood storage volume	Some treatment devices may provide for additional flood storage to assist in managing and mitigating downstream flood effects and flood risks during large, infrequent events. The flood storage volume (FSV) is the storage zone above the event detention volume (EDV) and provides flood storage only.
Flood water level	The flood water level (FWL) is the maximum height reached by the flood storage volume (FDV) during the design flood event.
Flow through system	A system where the inflows are equal to the outflows at all time. These will typically be used where there is a near constant flowrate such as with pumped systems.
Geosynthetic clay liner	A lining system made by sandwiching high grade clay minerals (typically bentonite) between layers of geotextile to be used in situations where natural clay liners are not feasible.
Green infrastructure	Refers to stormwater assets that use soils and vegetation to restore some of the natural process used to manage stormwater and provide for healthier urban receiving water systems.
Gross pollutant trap	A pre-treatment device used to capture large debris such as litter.
High flow bypass	The high flow bypass is required to ensure flows are reduced to mitigate damage to the treatment device from large storm events.
Hydraulic retention time	The time taken for a volume of water to pass through a treatment device such as a wetland.
Internal water storage	Sits below the invert of the bioretention device (ie raingarden) outflow pipe and is included to promote retention and provide a water source for plants during dry periods.
Life cycle analysis period	The number of years over which the analysis will run.
Life cycle cost	The life cycle cost is the sum of the acquisition and ownership costs of an asset over its life cycle from design, construction, usage, and maintenance through to disposal.
Life cycle costing	Life cycle costing (LCC) is the process for assessing the cost of a product over its life cycle or portion thereof.

Term	Definition
Life span	The functional life of the treatment device in years.
Life cycle analysis period	The period of time (in years) over which the life cycle costing analysis is conducted.
Macrophyte zone	The macrophyte zone (shallow and deep water plants) is the largest component of the treatment area within a constructed wetland. Water quality treatment is provided by emergent aquatic macrophytes (plants) growing in shallow water below the permanent water level (<500mm at PWL).
Net Present Value	The Net Present Value (NPV) is the present-day value of all future costs (ie the value of future costs when discounted back to the present time).
Overland flow path	The overland flow path (OLFP) is the route taken by stormwater when the existing stormwater network is overloaded.
Particle size distribution	The particle size distribution (PSD) is the range (and proportion) of specified grain sizes across respective sieve sizes used to define composition of soils. Important design component for raingarden filter media.
Permanent water level	The permanent water level (PWL) is the maximum height of the permanent water volume (PWV). It is set by the invert level of the wetland outlet structure. This water level is relatively constant between storm events and can only be reduced by evapotranspiration or harvesting. The PWL is calculated to accommodate the full water quality volume (WQV).
Permanent water volume	The permanent water volume (PWV) is the storage provided in the wetland main body below the permanent water level (PWL). The water in this zone does not drain out between events (but can reduce through evapotranspiration or harvesting) and is fundamental to support the biological processes within the wetland and anoxic substrate conditions.
Routine maintenance costs	Annual costs that relate to routine maintenance events such as mowing grassed areas, weeding, general inspections, etc.
Total acquisition cost	The total acquisition cost (TAC) relates to the design, planning, consenting and construction costs of a device.
Vehicles per day	Vehicles per day (VPD) is the average number of vehicles using a specified section of road in a given day. Often determined by vehicle counts or estimated based on road class.
Water quality flowrate	The water quality flowrate (WQF) is used to design inlet structures to enable devices to treat the required portion of stormwater flows. Flow exceeding the WQF will be bypassed around the device.
Water quality volume	The WQV is calculated to capture and treat 90% of annual stormwater runoff.
Water sensitive design	Water sensitive design (WSD) is a collaborative approach to freshwater management. It is applied to land use planning and development at complementary scales including region, catchment, development and site. Water sensitive design seeks to protect and enhance natural freshwater systems, sustainably manage water resources, and mimic natural processes to achieve enhanced outcomes for ecosystems and communities.

1 GENERAL INFORMATION

Constructed wetland at Waitangi Park, Wellington. The integrated design of Waitangi Park requires a high degree of collaboration between the operators of the treatment system and the park's other features. At times these relationships and responsibilities have not been well defined. Good collaboration will ensure optimal functionality into the future.

1.1 Purpose

This guideline:

- communicates our requirements for the design of stormwater treatment devices where these devices are going to be vested with our client councils and become publicly owned assets.
- provides best practice guidance for the design of stormwater treatment devices where devices are to remain privately owned.

The decision as to whether a stormwater treatment device should be publicly or privately owned is outside of the scope of this document. This should be discussed and agreed with our Land Development Team on behalf of the council during pre-application discussions as part of the consenting process.

1.2 Background

There is a growing recognition within the Wellington region that stormwater networks must be managed to help improve the water quality of the region's fresh and coastal waters.

The Natural Resources Plan (NRP) for the Wellington region sets out an objective to maintain or improve the existing water quality in accordance with the National Policy Statement for Freshwater Management (NPS-FM).

Water sensitive design (WSD) is a best practice approach to improve water quality that can also achieve a wide range of benefits for biodiversity, liveability and enhancing public spaces.

We support the use of better management practices through the release of standards, guidelines and technical practice notes.

This Water Sensitive Design for Stormwater: Treatment Device Design Guideline provides guidance:

- for the concept, preliminary and detailed design phases of a stormwater treatment system.
- to ensure new devices are functional, optimised, maintainable, safely designed and mindful of community values.

Before using this guideline, it is important to complete a site assessment. We intend to release further guidance to support this initial site assessment. Until such time, we recommend that the Auckland City Council Guideline Document, Water Sensitive Design for Stormwater (GD04), is used together with this guideline during the initial stages of design.

1.3 Definition of water sensitive design (WSD)

For the purposes of this guideline, water sensitive design is defined as:

"An approach to freshwater management, it is applied to land use planning and development at complementary scales including region, catchment, development, and site. Water Sensitive Design seeks to protect and enhance natural freshwater systems, sustainably manage water resources, and mimic natural processes to achieve enhanced outcomes for ecosystems and our communities."

(Auckland Unitary Plan)

1.4 Scope

This guideline provides technical advice on how to design and size four types of stormwater treatment devices:

- Constructed wetlands.
- Bioretention (raingardens).
- Vegetated swales.
- Pervious paving.

Alternative options or variations to the device specifications outlined in this guideline must be discussed and agreed in writing with the Land Development Team at Wellington Water.

This guideline does not:

- focus on the design of devices to be retrofitted into existing urban areas. These applications typically require specialist design to ensure that treatment outcomes are met.
- discuss the structural or architectural design considerations of each device.

We recommend that this guideline is used together with the guidance in Table 1.

Table 1: Recommended guidance for stormwater treatment design phases.

Design phase	Recommended guidance
Project scoping	Early engagement with Wellington Water's Land Development Team.
Site assessment	Water Sensitive Design for Stormwater (GD04), (Auckland Regional Council).
Concept design, preliminary and detailed design	Water Sensitive Design for Stormwater: Treatment Device Design Guideline (Wellington Water).

1.5 Other design guidance

This guideline must be used in conjunction with other Wellington Water design guidance and standards, including the following:

- Regional Standard for Water Services.
- Regional Specification for Water Services.

1.6 Subdivision requirements

Requirements relating to the overall subdivision process, urban planning, health and safety and other council utilities and services can be found in the council's existing subdivision codes and policy documents. Reference shall also be made to these documents and their requirements when planning works using this document.

When considering the stormwater infrastructure, this document specifically excludes:

- subdivision application and approval processes
- development contributions policy
- roading and roading reinstatement
- applications for connections to public services
- subdivision compliance certification
- detailed as-built specifications.

These requirements are detailed within each council's general subdivision codes or policy documents.

1.7 Legislative requirements

Any proposed infrastructure project must, as a minimum, comply with the following legislation where applicable, plus any subsequent amendments:

- Building Act 2004
- Local Government Act 2002
- Health and Safety at Work Act 2015
- Reserves Act 1977
- Resource Management Act 1991

1.8 Regulatory documents

In addition to the legislative requirements, the following regulatory documents are also to be referenced where applicable:

- Council's operative district plans.
- Operative council bylaws and charters.
- Operative and proposed Wellington Regional Plans.
- National Environmental Building Standards.
- The New Zealand Building Code.
- The National Code of Practice for Utility Operators' Access to Transport Corridors (and local conditions).

Other documents are also referenced throughout this document at the relevant section.

1.9 Health and safety in design

The requirements of the Health and Safety at Work Act 2015 and the Health and Safety at Work Regulations shall be observed at all times.

All designers so far as reasonably practicable must design all plant, substances or structures without risk to the health and safety of persons who use, handle, store, construct, or who carries out any foreseeable activity for inspection, cleaning, maintenance, or repair for the plant, substance or structure as designed, in accordance with the Health and Safety at Work Act 2015.

2 DESIGN PROCESS

Waiwhetū Stream, Lower Hutt. Waiwhetū Stream was named for its reflection of the stars on still clear nights and was an important mahinga kai (food gathering place). Today the catchment is highly urbanised and collects 40 percent of the total stormwater run-off from the Hutt Valley. In recent years, efforts have been made to restore the stream through riparian planting, infrastructure upgrades, contaminant removal and better land-use practices.

2.1 Performance requirements

The statutory context for managing stormwater is found primarily in the Natural Resources Plan (NRP) for the Wellington region and all discharges from council stormwater networks must be managed in accordance with a discharge consent granted under this plan.

In general, the performance requirements for managing stormwater discharges from the stormwater network include:

- progressive improvement
- using good management practice
- taking a source control and treatment train approach
- implementing water sensitive design.

Where appropriate, the performance requirements for specific stormwater treatment devices will be based on catchment-specific priorities identified in our stormwater catchment management strategies.

2.2 Concept design

The most important time to define stormwater treatment requirements, and how objectives will be achieved, is in the earliest stages of design, before developing rigid layouts and corresponding lot yields. This will typically be at the structure plan stage for larger developments.

Defining stormwater treatment requirements in the early stages of a project will ensure that:

- adequate provision is made for stormwater management.
- these requirements can be integrated with other design disciplines and the overall catchment stormwater management strategy.

The stormwater treatment concept design should be resolved before the pre-application meeting, with in-principle support from Wellington Water's Land Development Team.

2.2.1 Steps to support optimal WSD outcomes at concept design

The following steps in Table 2 support optimal WSD outcomes based on appropriate levels of design planning at the concept design stage.

Table 2: Steps to support optimal WSD outcomes at concept design.

Step	Description
1	**Bio-physical assessment** Complete a full site assessment to look at the existing and historical (pre-disturbed) ecological and hydrological conditions of the site including existing streams (intermittent and ephemeral), defined sub catchments, areas subject to flooding or seasonal waterlogging, significant ecological sites (both remaining and lost), downstream receiving environments and upstream habitats that may require connectivity. Refer to Section C of Water Sensitive Design for Stormwater (GD04) for further guidance.
2	**Socio-cultural assessment** Identify opportunities to use the site in terms of topography, relationship with waterways, existing soils to support infiltration and relationships between stormwater treatment and other design aspirations. This should involve a multi-disciplined design team including iwi representatives; urban/landscape design; planners and resource management practitioners; ecologists and engineers. Early and ongoing engagement with iwi representatives is particularly important at this stage to capture the values, aspirations and cultural connections of Maori to the specific site and ensure that this is appropriately reflected in the design of any devices. This must be recognised as an opportunity to enhance the overall project and support ongoing collaboration and understanding in the area of integrating cultural values with future urban development. This can add value to the project in terms of education, awareness of long term water related issues, understanding of need for better water quality and community connection. Where appropriate, stormwater treatment devices can also provide or support productive uses through harvestable materials or irrigation water. Careful consideration of all relevant planning policy and guidelines (such as District Plans) is required to align with other development requirements like provision of public open space, community facilities and transport infrastructure. Refer to Section C of Water Sensitive Design for Stormwater (GD04) for further guidance.
3	**Stormwater treatment concept** Complete an options assessment to determine the preferred treatment strategy and inclusion of any other private/public devices within the catchment. Consideration should be given to protect any existing natural resource areas and minimise the disturbance of native soils. Refer to section 2.3 and 2.4 for further guidance.
4	**Environmental framework** Confirm with Wellington Water's Land Development Team and/or the Greater Wellington Regional Council (GWRC) if there are any other relevant requirements on design such as flood attenuation; riparian ecosystem protection; restoration or fish passage. Consider opportunities to integrate any of these required improvements with the stormwater treatment.
5	**Assessment of potential impervious areas** Complete conceptual development layout with the wider design team to estimate expected levels of imperviousness, lot yields, road alignments and public open space/reserves relative to sub catchments. Look for opportunities to adjust the design to create effective transportation networks and desirable lot layouts while minimising impervious surface coverage. Refer to section 2.4 for further guidance.

Step	Description
6	**Treatment concept sizing** Conceptually size treatment devices in line with respective sections of this guideline. Add an additional 30 per cent area allowance if no earthworks model has been developed to quantify the additional space required over and above the treatment footprint for batters, access and hydraulic structures. Refer to section 2.4 and technical guidance sections 3 to 6 for further guidance.
7	**Conveyance and connection to the existing network** Complete further site assessment based on available survey, Lidar or any other digital elevation model to identify preliminary operating levels, optimal location on site and confirm upstream/downstream connection points.
8	**Integration with wider design team** Work iteratively with design team to integrate any stormwater treatment devices into the development with respect to road layout, reserves, public connections and community facilities.
9	**Concept design report and drawings** Produce concept design drawings showing the indicative layout of stormwater treatment assets and relationship with wider development. Prepare brief concept design report documenting all constraints, assumptions, design parameters and operating levels. This will clearly demonstrate how the proposed measures will meet long-term water quality objectives. Refer to section 2.6 for minimum documentation requirements at concept design stage.

2.3 Treatment options

Different devices will provide different treatment performance depending on the physical, chemical and biological processes used for these devices and their connection with the stormwater network.

Table 3 provides a summary of the potential treatment benefits of a wide range of devices. The four devices in black are those covered within this guideline, with those in green being other technologies that are not specifically covered.

Table 3: The treatment role of various stormwater management devices.

Stormwater management devices	Treatment role						
	Sediment	Metals	Nutrients	Temp/ph/DO	Frequent flow detention	Retention	Peak flow detention
Wetlands	✓	✓	✓	✓	✓	×	✓
Bioretention	✓	✓	✓	✓	✓	?	×
Swales	?	?	×	×	×	?	×
Pervious paving	✓	?	×	✓	✓	✓	×
Rainwater tanks	✓	✓	✓	✓	✓	✓	✓
Green roofs	✓	✓	✓	✓	✓	×	×
Rapid infiltration	✓	?	×	✓	✓	✓	×
Tree pits	✓	✓	✓	✓	×	?	×
Proprietary devices	✓	✓	?	✓	?	×	×
Open ponds and basins	✓	?	×	×	✓	×	?

✓ = Device provides management benefits.

? = Device may provide some management benefits dependent on design.

× = Device does not provide management benefits.

Table 4 (below) provides the estimated pollutant removal for wetlands, bioretention, pervious paving and swales that are designed in accordance with this guideline. The estimated removal rate is:

- based on the mean annual load into a system and the corresponding load reduction over that period.
- can be applied in instances where a treatment train is adopted or where estimation of development scale performance is required.

Table 4: Treatment performance of wetlands, bioretention (raingardens), swales and pervious paving (from NZTA Stormwater Treatment for State Highway Infrastructure).

Stormwater management devices	Estimated removal rates (%) for devices				
	TSS	Total Nitrogen	Total Phosphorous	Zinc	Copper
Wetlands	90	40	50	80	80
Bioretention (raingarden)	90	40	60	90	90
Swales*	60	20	30	65	50
Pervious paving	80	20	30	75	60

*Swale performance has been reduced to account for re-mobilisation of sediments in moderate to large events.

2.3.1 Device selection

Devices must be selected on careful consideration of topography, land use characteristics, receiving environment and overall urban design intent.

The selection of a particular device or suite of devices must consider:

- water quality benefits provided by the particular device and its ability to meet mitigation requirements
- optimisation of the number of devices
- design and placement for maintenance
- proposed ownership of device
- integration into the existing network and catchment management strategy
- safety in design
- resilience of the design to provide benefits over the long term
- additional benefits for biodiversity, liveability and enhancing public spaces depending on consultation with stakeholders and the characteristics of the area.

2.3.2 Stormwater treatment train

Stormwater management to achieve the desired performance requirement at the point of discharge can include several different devices at a range of scales.

This integrated system can be delivered as a fully distributed network of small devices or a smaller number of larger sub catchment scale systems. This can include devices in series where water quality and quantity improvements are provided throughout a development as flows travel from the upper most source to the downstream receiving environment. This is often referred to as a 'treatment train'.

These integrated systems must be designed to collectively deliver the desired water quality outcomes while reflecting the work of upstream devices.

When designing a treatment train using a combination of the devices covered by the technical guidance sections 3–6, the catchment and placement relationships between the devices in Table 5 (below) must be followed.

Table 5: Treatment train catchment and placement relationships.

Treatment train scenario	Catchment and placement relationships
Treatment devices downstream of wetlands	The sizing for treatment of any device placed downstream of constructed wetlands should exclude the upstream catchment areas treated by constructed wetlands, and account for only the contributing untreated catchment of the device. Bioretention devices must not be placed downstream of wetlands.
Treatment devices downstream of bioretention or pervious paving	The sizing for treatment of any device placed downstream of bioretention or pervious paving should exclude the upstream catchment areas treated by bioretention or pervious paving, and account for only the contributing untreated catchment of the device.
Treatment devices downstream of swales	The sizing for treatment of any device placed downstream of swales should exclude 50% of the upstream catchment areas treated by swales, in addition to accounting for any contributing untreated catchment of the device.
Design of diversion and bypass structures	The sizing of diversion and bypass structures must take account of the entire upstream catchment regardless of treatment.

2.4 Technical design and sizing

This section provides the methods used to design and size the treatment devices covered in sections 3–6.

The sizing calculations are based on treating the runoff from approximately 90 per cent of all annual stormwater runoff, which is also referred to as the Water Quality Volume (WQV). This volume will allow for the treatment of the 'first flush', which is known to be the most contaminated portion of flows and characterised by temperatures, pH and flowrates that are most harmful to the receiving environment.

The sizing of stormwater treatment devices is fundamental to their long-term function and efficient maintenance. Devices that are either undersized or oversized tend to require ongoing actions so they perform as intended. Common problems that occur as a result of incorrectly sized devices include scour from increased velocities and unacceptable rates of plant mortality from prolonged elevated water levels or insufficient inflows.

2.4.1 Contributing catchment area

The catchment area draining to a treatment device is the fundamental element to consider in the design at the outset. This enables designers to consider using multiple smaller systems or fewer large systems; and to determine if the device will be used as part of a wider treatment train approach or as standalone treatment for sub-catchments.

The method in Table 6 is recommended to define the contributing catchment areas used for sizing of treatment and diversion structures.

Table 6: Steps to define contributing catchment areas.

Step	Step description
1	Use drawings or a Geospatial Information System (GIS) to determine the full drainage catchment that will be conveyed to the device. This will include the immediate road and verges for streetscape systems but may extend to mixed land uses for larger systems including piped networks.
2	Delineate impervious land covers from the catchment. Identify all potential impervious areas including roads, pedestrian paths, carparks, dwellings, paved areas and any commercial areas must be identified. Initial estimates of the impervious land covers made at the concept design stage will be fine-tuned as the development is refined, so it's important to make allowance for possible increased imperviousness to avoid later changes and to verify the proposed impervious areas at conclusion of detailed design.
3	Delineate upstream areas to be fully treated within the catchment as part of a treatment train.
4	Define the full contributing impervious area that will discharge to the device excluding areas treated by other upstream devices.
5	Define the entire catchment that will drain to the device, include network and overland flow, in events up to the 1% Annual Exceedance Probability (AEP) (or greater if required by the Regional Standard for Water Services). This flow rate must be considered in the design to avoid damage or flooding.

2.4.2 Calculation of Water Quality Volume (WQV)

The calculation of the Water Quality Volume (WQV), to capture and treat 90% of annual stormwater volume is used to size wetlands at preliminary and detailed design in Section 3.

The capture of runoff resulting from ⅓ of a 50% AEP 24 hour rainfall event has been modelled to support treatment of approximately 90% of annual stormwater runoff. The WQV can therefore be calculated using Equation 1 and Equation 2 below.

Equation 1: Calculation of the effective impervious area.

$$A_{wq} = 0.95 \times A_{imp} + 0.15 \times A_{perv}$$

Where

A_{wq} = Effective impervious area (m^2)

A_{imp} = Impervious catchment area (m^2)

0.95 = Runoff coefficient for impervious landcover

A_{perv} = Pervious catchment area (m^2)

0.15 = Runoff coefficient for pervious landcover

Equation 2: Calculation of the Water Quality Volume (WQV).

$$WQV = \frac{1}{3} P_{50\%\,AEP\,24hr} A_{wq}$$

Where

WQV = Water Quality Volume (m^3)

A_{wq} = Effective impervious area (m^2)

$P_{50\%\,AEP\,24hr}$ = 50% AEP 24 hour rainfall depth (m)

The 50% AEP 24 hour rainfall depth must be sourced from the National Institute for Water and Atmospheric Research (NIWA) High Intensity Rainfall Design System (HIRDS), specifically for current climate conditions. No allowance for climate change should be included because the mean annual rainfall volume across the Wellington region is expected to remain relatively static over the next 50 years under all climate change scenarios available to Wellington Water.

2.4.3 Calculation of Water Quality Flowrate (WQF)

The Water Quality Flowrate (WQF) is used to size elements of wetlands, bioretention (raingardens), swales, and pervious paving in Sections 3–6.

The WQF is calculated using the rational method applied to a rainfall intensity of 10mm/hr. Through allowing inflows up to the calculated WQF and designing to bypass those that exceed this threshold, a device should capture an equivalent volume (WQV) to that calculated by Equation 2. This is particularly important where the inflow must be restricted to reduce the risk of damage to the stormwater treatment device from large storm events.

Equation 3: Calculation of the Water Quality Flow (WQF)

$$WQF = i_{const}\left(\frac{CA}{360}\right)$$

Where

WQF = Water Quality Flowrate (m^3/s)

i_{const} = Constant rainfall intensity 10mm/hr

C = Runoff coefficient as per Regional Standard for Water Services

A = Area of catchment (hectares) as per Regional Standard for Water Services

2.4.4 Design for stream protection, flood management and conveyance

Any design for flow management in addition to the water quality function of devices must comply with Wellington Water Regional Standard for Water Services, including but not limited to:

- bypasses and spillways
- hydraulic neutrality
- flood attenuation
- conveyance.

If flow management is to be included with the design for stormwater treatment, it is important that the details are discussed with Wellington Water's Land Development Team at the pre-application stage to ensure that the approach is suitable and that the design has allowed for adequate footprint.

2.4.5 Continuous simulation modelling approach

Wellington Water encourages the use of continuous simulation software for the modelling of more complex systems where devices are unable to be sized for best practice but combine with other devices to deliver the overall water quality objectives.

Wellington Water does not have a technical standard to support continuous simulation modelling. The designer must provide suitable climate data, based on locally derived rainfall data and evapotranspiration rates, and demonstrate to Wellington Water's satisfaction that it is appropriate for the given application.

2.5 Life cycle costs

A life cycle cost analysis must be completed to support detailed design using the process outlined in Table 7.

At concept and preliminary design it is acceptable to use the indicative rates (NPV $/Ha/yr) in Table 8 to enable easy comparison between treatment options.

2.5.1 Life cycle cost analysis – Description

Life cycle costing (LCC) is a well-accepted international method that is used to assess the costs associated with stormwater management devices. The life cycle cost is the sum of the acquisition and ownership costs of an asset over its life cycle from design, construction, usage and maintenance through to disposal (Figure 1).

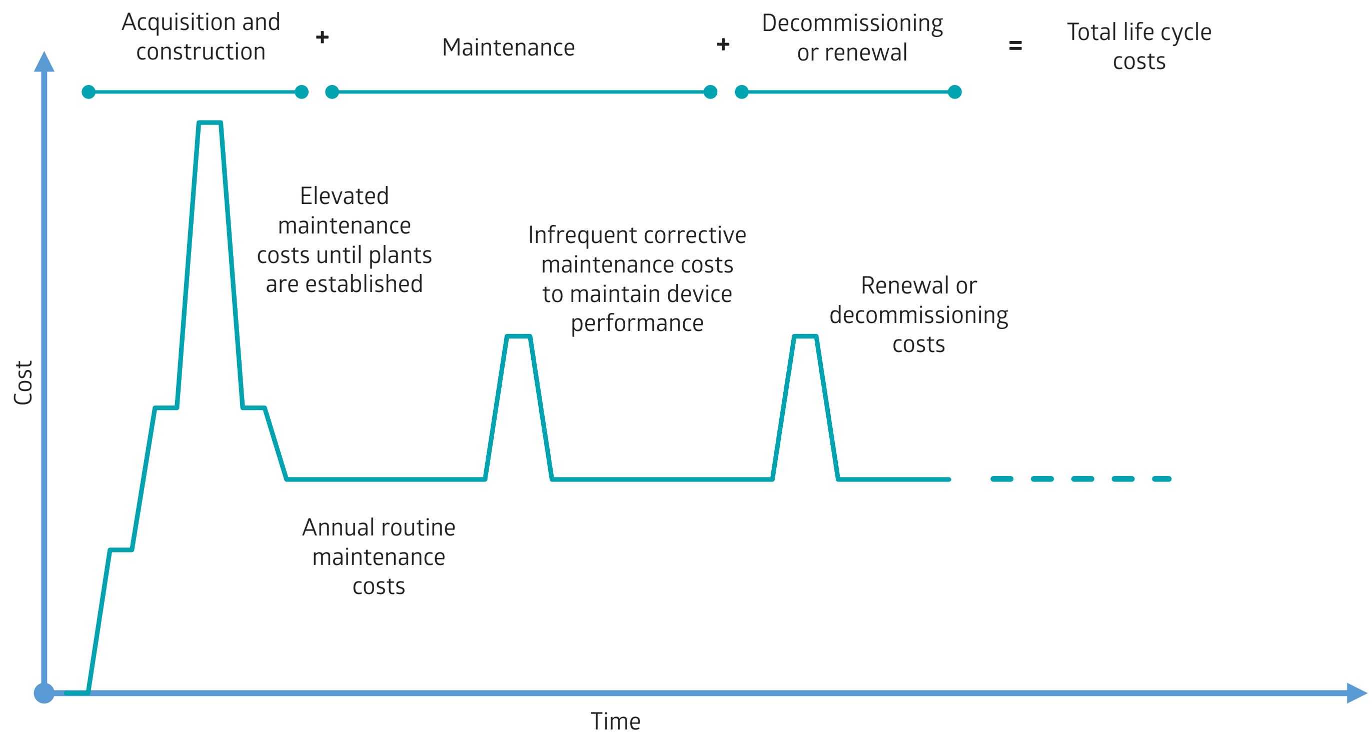


Figure 1: Phases in the life cycle of a stormwater device and potentially associates costs (adapted from Taylor, 2003).

Life cycle costs are normally expressed as either a total Net Present Value (NPV) over the life cycle of the device, or a NPV per year for each year of the device life span. The total NPV LCC is the lump sum amount that a person would need today to meet all the costs of installing, maintaining and using that device over its lifetime. A LCC analysis is not a financial analysis of asset depreciation over time. It makes no assumptions about the feasibility, timing, uptake or optimisation of stormwater management devices, nor about financing, governance or distributions of costs for particular catchments or activities.

2.5.1.1 Limitations

Whilst LCC analyses are reasonably common, the accuracy of any analysis is dependent mainly on the quality of cost data which is used. However, cost information is notoriously variable, difficult to collect and may rapidly go out of date especially with devices that are isolated or new to a region without economies of scale or understanding of construction, operation, or maintenance. The cost information provided within this guideline is based on 2018 dollar values and represents available cost information in New Zealand at the time of writing.

2.5.2 Step-by-step guide to undertaking a life cycle costing

This guideline provides an overview of the accepted methodology for LCC. Designers using this guideline should make use of their own cost data and technical assumptions when undertaking a LCC analysis. Table 7 shows a step-by-step guide to undertaking a life cycle costing analysis.

Table 7: Step-by-step guide to undertaking a life cycle costing analysis.

Step	Task	Assumptions/parameters
1	Identify the key design parameters	Design the stormwater treatment device in accordance with sections 3–6.
2	Decide on an appropriate life span	The life span varies depending on the type of stormwater treatment device and is the functional life of the device. For the devices specified in this guideline, a minimum of 50 years should be used for the life span.. Within this 50 years, devices can be renovated and renewed (e.g. mulch, plants and media replaced).
3	Decide on an appropriate life cycle analysis period (LCAP)	The LCAP is the number of years over which the analysis will run. It is usually equal to the life span. If multiple devices are being modelled as part of a treatment train approach, then the LCAP needs to be consistent so that the results across devices are comparable. A LCAP of 50 years is acceptable for comparisons of devices designed using this guideline.
4	Identify the base date for the cost data and, if relevant, the inflation rate	Cost data from different years can be used, but all original cost data should be inflated to the same base date before beginning a LCC analysis. No inflation of costs occurs during the LCC analysis. If costs do need to be inflated, the inflation rate recommended by Statistics New Zealand should be used (ie as calculated from the Business Index for the "Construction Industry" located at **https://www.stats.govt.nz/methods/price-indexes-for-the-construction-industry** Alternatively, the online Reserve Bank inflation calculator can be used: **https://www.rbnz.govt.nz/monetary-policy/inflation-calculator**
5	Select discount rate for the Net Present Value (NPV) LCC calculation	The total NPV LCC is the lump sum amount that a person would need today to meet all the costs of installing, maintaining and using that device over its lifetime. In other words, costs that occur later in time within the LCC cycle are given less weight than those that occur sooner. The discount rate (DR) is therefore used to bring future costs back to today's dollar values. Use a DR of 3.5% unless instructed otherwise by Wellington Water's Land Development Team.

Step	Task	Assumptions/parameters
6	Calculate the total acquisition costs (TAC)	The TAC relates to the design, planning, consenting and construction costs of a stormwater management device. It can include, among other things: · specialist design consulting fees · council consenting fees · project management fees · tender process fees · site establishment · materials · equipment hire · locating/breaking into existing services · traffic management · site clearance · earthworks/excavation · planting/landscaping · transportation · labour · clean-up · erosion and sediment control · inspections · land costs. A 'schedule of quantities' document or similar should be used to document TACs, including identifying the total acquisition activity identified, along with unit costs, units and total costs.
7	Calculate the routine maintenance costs (RMC)	These are annual costs that relate to routine maintenance activities such as general inspections, mowing grassed areas, weeding, cleaning out debris, making good from vandalism etc. Appendix A includes spreadsheets that provide guidance on the different types of routine maintenance activities for wetlands, raingardens, swales and pervious paving. Costs need to be specified for each item of maintenance identified, along with unit costs, units and frequencies of maintenance.
8	Determine the corrective maintenance costs (CMC)	These are costs associated with large-scale but infrequent maintenance activities. They include repairing parts, cleaning out sediments and disposal of them, replacing filter media, etc. Renewals can also form part of the corrective maintenance costs. Appendix A includes spreadsheets that provide guidance on the different types of corrective maintenance activities for wetlands, rain gardens, swales and pervious paving. Costs need to be specified for each item of maintenance identified, along with unit costs, units and frequencies of maintenance.
9	Decommissioning costs (DC)	If the device will be decommissioned at the end of the LCAP, these costs should be included. However, it is more likely that the device will continue to operate. If this is the case, then a full-scale corrective maintenance cost or renewal cost needs to be scheduled for the final year of the LCAP and decommissioning costs can be excluded.

Step	Task	Assumptions/parameters
10	Determine the LCC	Input all the relevant cost information into a LCC model and run the model to determine the NPV cost. This cost can be expressed as a total $NPV cost over the LCAP or it can be divided by the LCAP and expressed as a $NPV per year. An example calculation is shown in Appendix B for recording and assessing the LCC.

2.5.3 Indicative NPV LCC estimates

Based on currently available cost information, Table 8 provides a summary of the indicative LCC estimates to compare and optimise treatment options covered in this guideline at concept and preliminary design stages.

Constructed wetlands, bioretention (raingardens) and swale costs are provided as NPV costs per ha of treatment catchment area per year and are based on treating 90% of mean annual stormwater runoff. Pervious paving costs are provided as NPV costs per square metre of pervious pavement.

The cost estimates relate to the construction and maintenance of devices in greenfield development areas where site establishment; and preliminary and general costs, as well as a portion of the design, consenting and compliance costs are part of the overall subdivision costs rather than related to the devices themselves.

A cost range is provided to account for variation in construction and maintenance techniques, materials, soils, slope and maintenance activities.

Table 8: Indicative NPV LCC $/year cost estimates.

Device	Approximate NPV range (2018)	Unit	Assumptions	Approximate maintenance cost portion of LCC
Wetlands	$1,100– $1,300	NPV $/ha/yr	NPV $/ha/yr costs for a life cycle analysis period of 50 years using a 3.5% real discount rate and excluding land costs. The design rainstorm is one third of the 50% AEP storm event. MCs are estimated as a percentage of the total LCC.	10%–20%
Rain gardens	$4,300– $4,500	NPV $/ha/yr		35%–45%
Swales	$700–$850	NPV $/ha/yr		65%–75%
Pervious paving	$10–$16	NPV \$/m^2/yr		60%–70%

2.5.4 Optimising design to avoid common maintenance issues

Costs can also be avoided or saved during the maintenance phase, providing the device has been designed to facilitate ongoing maintenance. Table 9 provides a summary of the key influencers of spiralling maintenance costs relevant to all treatment devices covered in the guideline. In addition, each technical guidance section includes device specific guidance on designing for maintenance.

It is noted that many of the key influencers relate to care of the vegetation, inlets and outlets, traffic management and device shape/area requirements. In general, regular routine maintenance that is scheduled during the growing season and to occur after large rain events will reduce requirements for large scale corrective maintenance and renewals.

Table 9: Design related maintenance issues for green infrastructure and recommended fixes.

Design related maintenance issues	Recommended fix
Inlet and outlet design – the most common cause of high maintenance is poor inlet design or construction which lead to blockage. Blocked inlets and outlets prevent devices working and can lead to overloading of individual inlets and consequent erosion/ scour, at the overloaded inlets	Design all surface flow inlets for bioretention devices and/or swales to support safe and cost-effective maintenance. This includes: · rationalising the number of inlets (rather than having multiple small inlets that could block up) and ensuring that the inlets are accessible without conflict with high traffic roads that may require specific health and safety provisions · ensuring inlets and outlets are easily visible from vehicles where possible · designing for inlets to include a lowered deposition zone for any coarse sediments that will not result in blockages. · design self-cleaning inlets that allow flow into the device without initial sediment build up. These may have sheet flow or a vertical drop to erosion-resistant surface · design inlets that are not easily blocked by plant growth. Design hydraulic structures (especially any inlet/outlet controls) to be easily accessible for visual inspection. This includes outlets in wetlands and any diversions within the stormwater network. All such structures should have grated covers with accessible openings. Design all hydraulic structures including inlets, outlets, spillways and level spreaders to be resilient and not subject to scour. All spillways must include a concrete crest to ensure that scour does not result in progressive failure.
Inflexibility for operations can lead to costly interventions if design has not made allowance for future changes	Design weirs and flow controls to be adaptable and support future changes without significant expense. This is achieved by using removable (and adjustable) steel weir plates which can be re-cut or replaced in response to hydraulic function and potential future climate changes. Where devices are in proximity to the coast the use of stainless-steel fixtures must be required.
Device shape, depth and volume in relation to watershed influence how much stress the plants are under. Narrow devices surrounded by impervious surfaces are highly vulnerable, especially along roads and carparks	Ensure optimal device shape to reduce edge effects where possible; ensure plants that are vulnerable to breakages, especially trees, are not planted within reach of car bumpers.
People and vehicle pressure – unless designs physically exclude people and vehicles, then areas with high pedestrian counts are more vulnerable to damage and littering and need more maintenance to maintain aesthetics. Small rain gardens, protrusions and unprotected corners are highly vulnerable to physical damage and have higher maintenance	Use durable, sustainable edge protection measures that can withstand damage by vehicles and people (eg wooden bollards are easily broken as opposed to using natural rock boulders to stop vehicles driving on swales, industrial areas will require concrete). Avoid placing overflow grates where cars can hit them (eg on corners). Provide obvious, wide pedestrian crossing points that consistent with desire lines with dense plants on each side to discourage shortcuts. Use street furniture such as seats, rubbish bins, light stands to protect edges but put these outside the devices.
Lack of easy access to stormwater devices is a common problem, especially for wetland and pond forebays, and can cause maintenance delays and increased cost	Ensure that the design allows for safe access for the maintenance of all inlets, outlets and particular maintenance areas such as forebays. The provision of safe access must consider the safety of workers, the safety of the public and the interface with trafficable roads. For large devices such as wetlands, includes mown grass or designated sedge sacrifice areas where excavated sediment can be delivered and trucks loaded.

Design related maintenance issues	Recommended fix
Devices that require traffic management plans have high maintenance costs. Cones, spotters and attenuators are expensive and can increase maintenance costs threefold or more	Careful thought needs to be given to the location of the device, its inlets and sediment forebays within the road reserve as well as the need for traffic management during routine maintenance activities such as mowing, edge maintenance or weeding. In devices with limited number of inlets, these should be placed in areas that are safe and efficient to inspect and clean.
Placing services in devices, especially the base of swales and within rain gardens (lights, posts, signs) cause maintenance problems from people disrupting the device, eg by spraying or trimming and can block inlets. They also reduce the below-ground treatment volume of the device. Over-spraying can cause bare patches and die-off allowing weeds to infest the area	Ensure services are placed outside of stormwater treatment devices. Ensure retrofit signs, lights etc. are not placed in devices, and absolutely not within 1 metre of inlets or overflows.
Plant selection – plants not matching site conditions or planned maintenance – eg too tall or wide (requiring trimming) or too short and open (not able to suppress weeds). Mass planting of single species and clones of plants, increasing risk of catastrophic failure. Do not plant large-leafed deciduous trees in or adjacent to devices without planning and budgeting for Autumn leaf removal and increased inlet frequency	Specify groundcover species that will reach required height and maintain a density that will exclude weeds. Obtain the assistance of an ecologist or landscape architect to ensure a suitable landscaping plan is developed.
Aesthetic requirements – in most cases, high aesthetics is usually linked with higher maintenance costs. However, the highest level of maintenance occurs in beds that have annual plantings (no stormwater devices should have annual plantings as they cannot be sustained) or floral displays that require dead-heading	Use native plants and non-deciduous trees to reduce maintenance requirements. Trees usually lower the maintenance requirements of groundcovers underneath them but will require canopy lift to ensure light levels remain high enough to sustain a dense, weed-resistant groundcover.
Initial establishment success and weed competition – adequacy of initial care and hardening off of plant materials. Plants should reach a high cover (>80%) that can be sustained	Ensure that maintenance of vegetation and adequate cover of weed-excluding mulch is included in the defect's liability period and responsibility for plant maintenance is established.
The moisture content of disposed material has a significant effect on disposal costs. The wetter the mixture, the greater the weight of the material and therefore the higher the cost	Design set aside areas that can be used to place, dewater or dry out sediment which has been removed from the treatment device.
High sediment loads require more maintenance to maintain performance	This can be mitigated by enforcement action to prevent sediment generation from sources (silt fences, mulching, etc.), using forebays to capture sediment or using swales as pre-treatment devices. Areas near roundabouts or landscaping yards would be expected to have more spills of soils/mulch and compost than other areas.

2.6 Design development

This section covers the minimum requirements at each stage of design development from concept through to preliminary, and detailed design phases for a development of 11 or more lots.

2.6.1 Concept design

A concept design for stormwater treatment will need to be discussed with Wellington Water's Land Development Team in advance of the pre-application meeting.

The concept design report and set of drawings must show evidence of the concept design components in Table 10.

Table 10: Concept design components.

Concept design component	Reference section
Site assessment of bio-physical and socio-cultural attributes of the site	Section C of Water Sensitive Design for Stormwater (GD04).
Resource mapping that integrates the features of the site assessment into one or more drawings	Section C of Water Sensitive Design for Stormwater (GD04).
Site analysis including project objectives, environmental and development frameworks, and a review of the site context	Section D of Water Sensitive Design for Stormwater (GD04).
Definition of the mitigation requirements	Section 2.1, District Plan, Natural Resources Plan, and relevant District Council strategies and guidance documents.
Stormwater treatment concept, sized in accordance with this guideline and including an additional allowance for accessways, batters, and any hydraulic structures	Section 2.3, 2.4, and technical guidance Sections 3–6.
Proposed ownership model	In consultation with the proposed owners and Wellington Water's Land Development Team.

2.6.2 Preliminary design

Preliminary design will generally be required to support an application for a Resource Consent.

The preliminary design report and set of drawings must show evidence of the preliminary design components in Table 11.

Table 11: Preliminary design components.

Preliminary design component	Reference section
Refined treatment design based on detailed sizing for flow and/or volume metrics	Section 2.4 and technical guidance Sections 3–6.
Treatment device placement	Technical guidance Sections 3–6.
Safety in design risk assessment	Technical guidance Sections 3–6.
Lifecycle cost analysis	Section 2.5.
Connection to conveyance network	Regional Standard for Water Services.

2.6.3 Detailed design

Detailed design will generally be required to support an application for engineering/building consent approval.

The detailed design report and set of drawings must show evidence of the detailed design components in Table 12.

Table 12: Detailed design components.

Detailed design component	Reference section
Confirm design objectives have been met	N/A
Any testing or verification	Technical guidance sections 3–6.
Finalised device placement and sizing	Technical guidance sections 3–6.
Planting plan	Technical guidance sections 3–6.
Lifecycle cost analysis	Section 2.5.

3 CONSTRUCTED WETLANDS – TECHNICAL GUIDANCE

Stormwater outfall at Onepoto Arm, Porirua. Te Awarua-o-Porirua (Porirua Harbour) has played a fundamental role over generations in sustaining the region's physical and cultural needs. The water quality in the harbour has been significantly degraded and can no longer be used as a mahinga kai due to public health concerns. National, regional, and district leaders all have a role to improve the situation for future generations.

3.1 Introduction

This section provides technical guidance for the design of constructed wetlands for stormwater treatment and attenuation purposes.

Constructed wetlands are complex shallow-water environments that use a combination of physical, chemical and biological processes to remove contaminants from inflowing and captured stormwater runoff. Wetlands are resilient to a range of operating conditions and are well suited to being integrated with addition detention storage.

3.1.1 Scope exclusions

This guideline does not cover:

- saline wetlands, floating wetlands, subsurface wetlands or open water ponds
- ephemeral wetlands (where there is no permanent pool between rainfall events).

Wetlands covered in this guideline are not intended for treating trade waste discharges, agricultural/horticultural runoff or high sediment loads from construction sites. These situations require specific design considerations and an understanding of operational requirements, which are not included as part of this guideline.

3.1.2 Basis of design

This design methodology:

- recognises the critical role of vegetation in the performance of wetlands and aims to avoid the circumstances where online, deep open water ponds are constructed with the intent for them to perform as vegetated wetlands
- is intended to support better long-term water quality improvements, reduce maintenance and support better amenity and biodiversity outcomes
- is based on Auckland Council's GD2017/001 and TR2013/018 with amendments for preliminary sizing based on regional conditions.

3.2 Constructed wetlands – description

3.2.1 Benefits and functions

This section provides background to the benefits and functions of constructed wetlands.

3.2.1.1 Water quality improvement

Key constructed wetland treatment processes and functions can be summarised as follows:

- Coarse sediments are settled out in the sediment forebay and removed as part of the maintenance regime.
- Algal biofilms grow on the plant stems in permanent water and trap suspended fine particulates entrained in the water column. As biofilms slough off and sediment settles in between plants, associated contaminants are assimilated physically and chemically within root masses and detritus.
- Plant root zones help maintain an oxidised sediment surface layer that prevents undesirable chemical transformation of settled contaminants.
- Soil microbial populations support important transformations of nitrogen, iron, sulphur and carbon.
- Wetland soils act in cation-exchange, chelation of heavy metals, sorption and chemical decomposition of harmful substances.
- Plants use nutrients and absorb some dissolved contaminants.
- The complex structure of wetland vegetation and its ability to lie flat and protect underlying substrates reduces the risk of scour and flushing out of biofilm and trapped sediments; biofilm is also quick to re-form on any areas that have been scoured.

- Vegetation increases roughness and promotes uniform flow through the wetland, maximising filtration processes and detention times. Densely vegetated wetlands buffer temperature increases attributed to stormwater runoff from paved impervious surfaces and standing bodies of open water.

A constructed wetland is a living treatment system relying on biological activity, so water quality improvement efficiencies can vary with seasonal fluctuations associated with plant, animal and microbial metabolic activity. An understanding of these biological and chemical processes is important to maximise wetland design and treatment efficiency.

The hydraulic efficiency within a wetland is based on maximising the contact time of untreated water with the wetland vegetation and the contaminant removal mechanisms that it supports. This can be achieved by ensuring that short-circuiting is avoided and that flows are dispersed across the full width of the wetland to promote this contact.

Careful consideration must be given to the velocity of inflows and duration of inundation to ensure that the treatment function is not compromised. This is achieved through design of constructed wetlands as offline to the primary network flow path and managing flood detention to control potential scour and stress on vegetation.

Figure 2 shows an aerial perspective of a recently planted wetland constructed offline to the high flow channel, with inlet and forebay to the left, maintenance access and integrated pedestrian pathways/boardwalks.

Figure 2: Example of recently planted constructed wetland integrated with public park and adjacent properties. Brylee Reserve, Auckland.

3.2.1.2 Water quantity control

Constructed stormwater treatment wetlands provide long term ecological protection to downstream receiving environments. They provide this protection through the buffering of ‘flashy’ flows during frequent small rainfall events that are detained within the wetland and released at a slower rate, more comparable to a natural catchment character.

Constructed wetlands can also be readily configured to provide attenuation of flowrates in moderate/large events. They do this by providing temporary storage and controlled discharge during infrequent large rainfall events, to reduce the risk of downstream scour and flooding.

Figure 3 shows a wetland constructed within a larger flood detention basin with overflow in foreground. The degree to which flows are attenuated depends on the design storm for which the wetland was designed, storage volume and the outflow characteristics.

Figure 3: Example of wetland positioned in the base of a larger scale flood detention basin.

The design of wetlands must consider the inflow rates and the design of the inlet, with the inclusion of a high flow bypass important to prevent damage to wetland plants and the biological processes that they support. Flow velocities through the wetland must be well managed to reduce the risk of scour of plants and biofilm or the resuspension of entrained sediments.

3.2.1.3 Landscape amenity

Landscape amenity is key to the overall success of wetland design and construction projects and should be considered throughout the design process. Where feasible, landscape amenity should include input from qualified landscape architects/urban designers from the initial concept design stage. Figure 4 shows a good example of landscape amenity provided by a constructed wetland in an urban setting.

Figure 4: Contemporary wetland providing natural character in an urban context. Waitangi Park, Wellington.

3.2.1.4 Habitat provision and biodiversity

The main purpose of constructed wetlands is to treat stormwater rather than to create habitat or mitigate for loss of aquatic habitat as a result of development.

Biodiversity outcomes are generally site specific and restoration objectives need to be addressed on a case by case basis, which is beyond the scope of this guideline. While wetlands may provide significant ecological benefits, their implementation cannot be used to offset or justify transformation of existing natural habitat, wetland or otherwise. Likewise, it is noted that maintenance of wetlands may require infrequent de-watering and sediment removal, which can impact on wetland flora/fauna and require re-planting. Therefore, wetlands are not intended as ‘natural’ systems that could trigger consenting issues.

Constructed wetlands are typically subject to more frequent and variable inundation events than natural wetlands and may not provide suitable habitat for sensitive wetland plant species. Species that do persist and flourish in constructed wetlands are generally more robust and adapted to a broader range of hydrologic variability. Constructed wetlands are therefore unlikely to achieve the same high levels of diversity that can be found in natural wetlands, although biodiversity value can be maximised through sensitive ecological design.

3.3 Main components

The main components of a constructed wetland are listed in Table 13 and shown in Figure 5 below.

Table 13: Constructed wetland main components.

Item	Description
Shallow and deep water plants (emergent macrophyte zone)	The macrophyte zone is the largest component of the treatment area within a constructed wetland. Water quality treatment is provided by emergent aquatic macrophytes (plants) growing in shallow water below the permanent water level (<500mm at PWL).
Forebay	The wetland forebay provides coarse sediment removal prior to runoff entering the main wetland body. The forebay area should be sized at 10% of the main body area with the volume of the forebay counting towards the WQV and the EDV.
High flow bypass	The high flow bypass becomes active when the flow rate exceeds the capacity of the device's inlet structure of the volume of runoff or exceeds the storage provided by the treatment device. The bypass must have capacity to convey the peak flow in a 1% AEP event (or greater if required by the Regional Standard for Water Services). The high flow bypass can be configured to engage the FSV (additional flood storage volume) above the EDV, in the wetland when required.
Maintenance access	A four metre wide dry weather maintenance access track must be provided to the sediment forebay to allow access for equipment to dig out the forebay. Vehicle access must also be provided to all hydraulic structures (inlet/outlet) and pedestrian access provided around the perimeter. Anywhere where blockages could result in flooding of properties maintenance access must be all weather access.

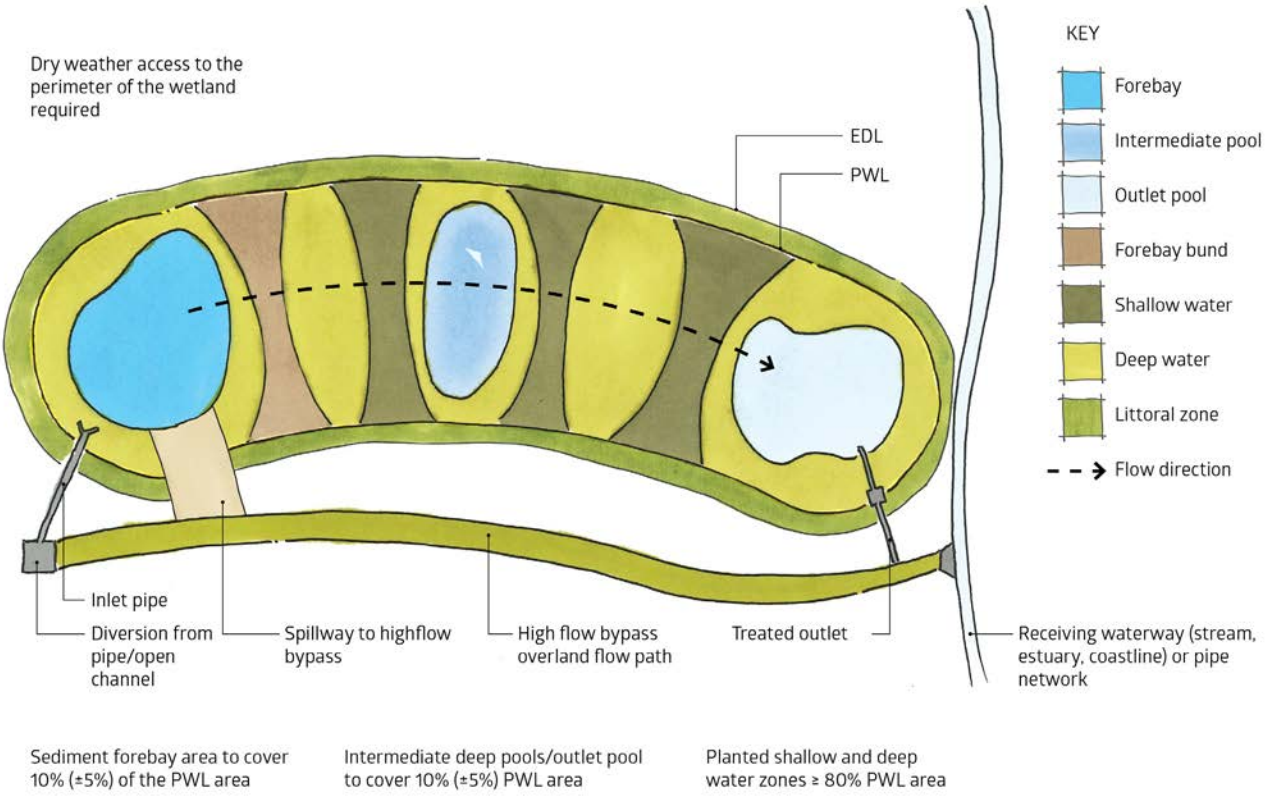


Figure 5: Schematic of main constructed wetland components.

Further detailed design guidance for each component is provided in Section 3.4.3.

3.3.1 Ecological zones

A constructed wetland is made up of a central treatment area that is engaged during frequent rainfall events and its surrounding terrestrial riparian area.

The central treatment wetland area is broken down into three ecological zones:

- shallow and deep water plant zone (emergent macrophyte zone)
- littoral zone (event detention volume)
- intermediate open water areas.

Each of the three central ecological zones is characterised by their water depth at permanent water level (PWL) and during storm events. The different water depths are specified to:

- satisfy the operational requirements of the vegetated wetland for water quality volume, physical and biological filtering processes, and event detention volume
- provide a greater range of habitats for wetland communities to become established.

The surrounding terrestrial riparian zone, which is typically dry, can enhance local biodiversity, provide further flood detention (FSV) and integrate the wetland into nearby landscape settings.

Each of the four wetlands zones are discussed in the following sections.

3.3.1.1 Shallow and deep water plant zone (emergent macrophyte vegetation area)

The shallow and deep water plant zone (emergent macrophyte vegetation area) includes dense emergent vegetation growing within shallow water (<500 mm at PWL). It is the main water quality treatment zone within vegetated wetlands.

The dense fibrous emergent wetland vegetation slows the water flowing through the wetland, disperses flows and allows suspended material to precipitate out. Importantly, the vegetation also provides attachment sites for biofilms that grow on the outside of both live and dead plant material. Biofilm sloughs off over time, assimilating within the stems and roots on the bed of the wetland. Litter that accumulates as a result of plant growth and senescence:

- provides additional organic material to the wetland
- creates additional ion exchange sites for chemical reactions and attachment sites for biofilm
- provides a source of organic material for microbial processes and feeding biota.

3.3.1.2 Littoral zone (event detention volume)

The littoral zone is located around the perimeter of the wetland immediately next to the emergent vegetation zone. This zone represents the area that is above the height of the PWL and is only submerged during frequent small rainfall events. The extent of the littoral zone is determined by the depth selected for the event detention volume (maximum depth of 0.35m as per Table 17).

This zone supports a transitional community of plants between fully aquatic emergent vegetation and terrestrial dry vegetation. Plants in this zone are well adapted to damp, often saturated soil conditions and are capable of withstanding short periods of inundation during storm events, but typically require drawdown to below the stem base between events. This zone provides only limited water quality treatment, but is critical to stabilise the perimeter, prevent unintended ingress to the wetland, provide riparian habitat and to support landscape amenity.

Figure 6 shows an example of an establishing littoral zone between the wetland and adjacent public walkway.

Figure 6: Established littoral zone above normal water level.

3.3.1.3 Intermediate open water areas

Small deeper pools nested within the shallow and deep water plant zone provide a range of benefits including additional settling areas; treatment in substrates (anoxic conditions); and reduced velocities on tight curves. These benefits promote mixing of flows and habitat diversity.

While deep pool habitat contains water too deep for rooted emergent vegetation, it can be suitable for submerged macrophytes and floating plants. The density of emergent plants generally decreases with water depth and emergent vegetation is unlikely to establish in pools deeper than 0.5m (especially with increased turbidity).

Figure 7 shows an intermediate pool located on a sharp bend within a wetland.

Figure 7: Intermediate deep-water pool.

3.3.1.4 Terrestrial/riparian zone

The terrestrial zone includes all areas that are not subject to frequent water storage functions. This zone may provide flood storage/detention (i.e. accommodate the FSV) for larger infrequent storm events, but only where wetlands are designed to also perform a flood mitigation function.

Vegetation in the terrestrial zone does not need to be adapted to water-logging due to an absence, low frequency, or low duration of inundation. However, this zone should include species that are typical of riparian locations such as stream sides and lake edges.

This zone also incorporates elements such as maintenance access ways, pedestrian pathways, landscape nodes and any surrounding buffer zones. Where the wetland includes provision for infrequent flood detention, the levels of protection from inundation for any publicly accessible areas (such as walkways, boardwalks or seating areas) must be discussed and agreed with Wellington Water in advance.

This zone can also include peninsulas extending into the wetland to lengthen flow paths (create sinuosity) and allow for maintenance access. Figure 8 shows an example of native planting around this terrestrial riparian zone.

Figure 8: Riparian planting around perimeter of wetland.

3.4 Constructed wetlands – design

3.4.1 Design considerations

This section provides guidance on the key design factors that must be considered during design of a constructed wetland.

3.4.1.1 Site selection

Constructed wetlands should not be located within the natural stream bed and must be constructed off line to the primary flow path of any watercourse or primary stormwater reticulation. This requires the careful design and construction of a diversion structure to divert the target runoff into the main wetland, while allowing excess flows to continue downstream.

Constructed wetlands do not require constant baseflows and will generally achieve better treatment performance where they receive only event-based stormwater inflows. Figure 9 shows the inlet to a wetland constructed offline to main flows. A weir controls flow to the wetland bypass channel to left in Figure 9.

Figure 9: Inlet to constructed wetland showing diversion from online channel to wetland forebay. Brylee Reserve, Auckland.

Wetlands are typically placed at the downstream end of sub-catchments due to topography and space requirements, but they can easily be integrated throughout development areas if urban design allows.

Wetlands should not be located upstream of bioretention elements due to the prolonged discharge from wetlands which can oversaturate bioretention systems resulting in root rot and malfunction.

Wetlands can be designed to integrate into a range of landscape contexts, from naturalistic features to contemporary landscape design elements.

Designers should consider the wider context of the site while ensuring the items in Table 14 are factored into the design.

Table 14: Site considerations.

Item	Consideration
Drainage	Ensure that the target catchment is able to drain to the wetland, preferably through a single inlet with an invert that enables the footprint to be achieved with efficient earthworks. • Where the inlet will be subject to backwatering during operation, checks must confirm that this will not result in upstream flooding. • Ensure that the proposed outlet level (ie invert of receiving drains and/or watercourse) will enable gravity drawdown of the wetland to at least the PWL between rainfall events.
Maintenance access	Consider how machinery will get access to the wetland for construction and maintenance, in particular, to clean out the sediment forebay. • Provide appropriate dry weather maintenance access to the forebay. • Provide key hydraulic structures and all-weather access to any structures where blockage could result in flooding to property.
Pre-treatment	Ensure that a dedicated sediment forebay is incorporated into the design. • Where industrial or high sediment generating business premises are included in the catchment, additional pre-treatment may be required by Wellington Water or GWRC.

Item	Consideration
Offline	Stormwater treatment wetlands must be placed offline to the main reticulated or channel flows.
Draw down	Wetlands must be free draining by gravity to at least the PWL. · Where possible, allowance must be made for draining the wetland further for maintenance purposes or to enable periodic water level management. · The forebay must be able to be drawn down (through siphon, pumping or gravity) in isolation from the remainder of the wetland, to facilitate cleanout.
Lining	Wetlands must be lined with an appropriate impermeable liner to prevent water losses and ensure water is retained at the PWL between events. · Lining can be either compacted natural clay (in situ or imported) or synthetic products such as geosynthetic clay liners (GCL) in accordance with manufacturer's specifications. · Where synthetic liners are proposed, designers must consider the stability of edge batters and compatibility with operations tasks.
Water table	Where wetlands are to be constructed above shallow water tables, attention must be given to constructability and issues with lining. It may be necessary to time the construction for low groundwater conditions or using synthetic liners.
Underground services	Designers must check the presence of utilities (power, water, gas, telecommunications) with the site owner and relevant utility companies. · If underground services are near or in the proposed wetland location, it would be preferable to relocate the wetland away from these services. · If relocating is not an option due to site constraints, seek agreement on solutions from asset owners/managers.
Setback	Constructed wetlands will require a minimum setback from proposed or existing structures of three metres. Refer to the following section for further detailed guidance on the setbacks in relation to geotechnical considerations.
Overhead setback	If trees are included around the wetland perimeter, designers must consider overhead setbacks to ensure that mature trees do not interfere with utilities such as power lines. · Designers must consult with relevant utility managers for up to date guidance on setbacks and so on. · Where the wetland is proposed beneath high voltage lines, designers must follow all relevant guidelines and standards.
Contaminated land	Lined wetlands can be suitable for location on top of contaminated land. Contaminated land may however pose a financial risk due to the potentially large amount of material to be disposed in construction of wetlands. · Designers must consider potential land contamination at the concept design phase and must also complete investigations, particularly where wetlands are proposed on historical fill locations.

3.4.1.2 Geotechnical guidelines for constructed wetlands

The geotechnical guidelines in Table 15 must be applied in the design of constructed wetlands.

Table 15: Geotechnical guidelines for the design of constructed wetlands.

A: Can the wetland alter the natural groundwater levels?	**Yes**	This type of wetland is not covered by this guideline. Seek specialist geotechnical advice.
	No	The devices will be fully lined – therefore no influence on groundwater as solely collecting rainwater and surface water flow.
B1: Are you building an embankment to contain the water?	**Yes**	It may be classed as a dam. See *Building Act 2004 Subpart 2 Interpretations* for definition of a dam. Dam safety requirements of the Resource Management Act 1992 and the New Zealand Building Act 2004 must be met. The source area for embankment material must undergo pre-characterisation testing for suitability for use as engineered fill.
	No	See B2.
B2: Are you excavating to create the ponding area?	**Yes**	Will the base of your lined wetland be lower than the natural groundwater table? If so, you will need to re-site pond area to above the natural groundwater levels to avoid uplift. Or alternatively, seek engineering advice to combat uplift forces.
	No	See C.
C: Is the wetland on a slope >5^0?	**Yes**	Geotechnical investigations are needed across the entire design area to understand the underlying soils, and designs must accommodate all geotechnical constraints (such as soil instability). Seek professional geotechnical advice.
	No	See other questions.
D: Is the wetland adjacent to or nearby any structures or foundations (includes roading and horizontal infrastructure)?	**Yes**	Minimum setback of 3m is required. In addition, on flat ground, setback to the edge of the structure foundation should be at least 1.5x the maximum wetland depth, eg a 3m deep wetland must be no closer than 4.5m to the nearest structure foundation. This setback may be able to be reduced with the advice of a geotechnical professional. On sloping ground see C..
	No	See other questions.
Other items		When geotechnical investigations are needed, they must be across the entire design area to understand the underlying soils, and designs must accommodate all geotechnical constraints (such as soil instability). All natural-hazards, loading conditions, potential failure modes and any other threats to the safe design, construction, commissioning, operation and rehabilitation of a dam should be identified. Wetlands should not be located upslope of existing or planned dwellings.

3.4.1.3 Retrofit designs

This guideline is primarily intended to support the design of new wetland systems (in greenfield development situations). However, the principles and design attributes can be incorporated into the design for situations where remedial retrofits of pre-existing constructed wetlands are required, or where new wetlands are proposed within established catchments.

In many instances, it will not be feasible to satisfy WQV requirements when designing retrofit solutions so it is important to engage early with Wellington Water's Land Development Team to agree an acceptable approach.

3.4.1.4 Safety in design

A constructed wetland contains multiple areas with standing water at variable depths. As a result, public safety considerations must be incorporated into the design. This is achieved through the inclusion of perimeter safety benches and compliance with the Building Code for all structures.

The main safety measure for constructed wetlands is a 2m wide densely planted safety bench with a 1V:8H grade to a depth of 250mm from the PWL.

The bench must be incorporated around the entire perimeter and prevent access to deeper sections of the wetland.

Other wetland safety considerations are as follows.

- The slope of the internal banks below the safety bench must be no steeper than 1V:3H, to allow easier access from the wetland should someone fall in.
- Perimeter batters above the PWL must be no steeper than 1V:4H.
- Dense low planting along path edges above slopes to deeper sections.
- Adherence to Crime Prevention Through Environmental Design (CPTED) principles to reduce risk to public through maintaining sight lines and so on.
- Ensure that all inlets, outlets, pre-treatment areas and maintenance areas do not pose undue risk to the public.
- Ensure that all flow paths (including high flow bypass) do not pose undue risk to the public during flood conditions. In particular, ensure that any grates and headwalls on culvert openings cannot cause persons to be trapped if they fall into flowing water.
- Consider impacts on public access paths during routine maintenance activities.
- Consider maintenance vehicle movements onto public roads and implications for traffic management planning.
- Clear illustrations within signage.
- Interim fencing and signage during development.

Permanent fencing is not preferred due to aesthetic impacts and general restrictions for access and interaction compared with more natural safety measures, however, it may be considered in the following circumstances where:

- perimeter batters are steeper than 1H:3V
- vertical drops exceed 1.0m
- permanent water deeper than 0.3m is next to heavily used areas (eg pedestrian walkways)
- the surrounding area is specifically intended for use by small children (swings, playgrounds, sporting fields and so on). In this case, a pool fence (or similar) should be used.

3.4.1.5 Dam safety considerations

In many instances, constructed wetlands may be designed to temporarily or permanently hold back water above the natural ground level through the use of bunds, embankments or dams. This design is typically applied to make use of the pre-existing site topography and avoid excessive excavations. Impounded water can pose a risk to downstream property and people, and the appropriate level of due diligence and technical expertise must be applied to the project.

The Building Act (Building (Dam Safety) Regulations 2008) has specific controls to manage risks around "Large dam" construction. A "Large dam" means a dam that has a height of 4 or more metres and holds 20,000 or more cubic metres volume of water or other fluid. The Act sets out how it must be measured:

The height of a dam is the vertical distance from the crest of the dam and must be measured,

(a) in the case of a dam across a stream, from the natural bed of the stream at the lowest downstream outside limit of the dam; and

(b) in the case of a dam not across a stream, from the lowest elevation at the outside limit of the dam

The impounded water volume should be measured as the maximum volume that could be free draining in the event of a breach of any retaining embankment. This includes water detained as part of any flood attenuation function of the wetland. The construction of any retaining structure that is considered to be a large dam as defined above will:

- require a building consent
- require design by a suitably qualified geotechnical engineer
- trigger a range of risk assessments and reporting.

Specific technical design requirements for constructed wetlands that fit the classification of a "Large dam" are not included in this guideline.

Notwithstanding the dam classification, wetland designers must always consider the implications of a sudden failure of the wetland embankment. The designer should ensure that the design, specification and construction of embankments, walls or other impoundment structures complies with the Building Act requirements. This applies where it is considered that such a failure could result in unacceptable risks to downstream property or people (based on process documented in the Building (Dam Safety) Regulations 2008).

3.4.1.6 Sustainability in design

Sustainability in terms of the materials used, scale of earthworks and lifecycle considerations must be considered from the outset of wetland design. This is important to ensure that assets are efficient (in terms of resource use) and are designed to reduce the impact on the regions carbon emissions.

The final design of wetlands can have big implications for the overall earthworks volumes and therefore the cost/carbon footprint to transport material offsite. Earthworks volumes should be considered from the outset of the design process to deliver efficient wetland designs.

Figure 10 shows a before and after picture of a wetland integrated into a public park, with the design minimising the extent of earthworks.

Figure 10: Before and after of wetland in public park. Brylee Reserve, Auckland.

Sustainability principles must be embedded in the design of constructed wetlands as follows.

- Aim to reduce the volume of bulk earthworks to be transported offsite by working with the site topography to develop an efficient form. Look to reuse as much material as possible within the immediate project area. Take care to ensure that any filling next to the wetland does not inadvertently reduce flood storage or overland flow paths with downstream impacts.
- Ensure that the design of all structures considers the full asset lifecycle and will not be expected to degrade or fail in less than the 50 year design life.
- Use in-situ or imported natural clay soil for wetland lining where appropriate. Decisions on the preferred lining option must consider:
  - the constructability (clay not suitable for compaction on saturated soils)
  - increased earthworks volumes (clay requires 300 mm)
  - carbon footprint of transportation
  - any implications where contaminated soil may be present.
- Look to use locally eco-sourced plant stock where feasible.

3.4.2 Technical device sizing

This section provides guidance for the sizing of constructed wetlands for concept and preliminary design.

3.4.2.1 Wetland sizing at concept design

The wetland must be sized at the conceptual stage of development in coordination with other layout considerations such as roading, lot layout, bulk earthworks and public open space. See Table 16 for critical sizing information.

It is important to ensure that sufficient space is allocated for the wetland at this stage to avoid conflicts at later stages where layout changes may be required. At this stage the operating levels (PWL, EDL and FWL) must be defined based on verified network levels, Lidar or topographical survey of the proposed development site. This will define how the system will operate hydraulically and confirm compatibility with other critical infrastructure.

Concept sizing can be based on:

- the simplified catchment method related to contributing catchment area (with a factor applied for ancillary earthworks), or
- calculation from the required water quality volume and supporting earthworks modelling.

3.4.2.2 Simplified catchment method

The simplified catchment method is intended to enable the required footprints for constructed wetlands to be estimated based on the imperviousness of the contributing catchment area which drains to it. This estimate:

- enables adequate space to be allocated for stormwater treatment within development layouts at the concept stage
- can support decisions around any additional flood attenuation requirements, public open space, landscape/urban design and civil infrastructure.

Table 16 shows the relationship between the wetland surface area (measured at PWL) and the imperviousness of the contributing catchment that can be used at the conceptual design stage.

Table 16: Relationship between wetland surface area and imperviousness of contributing catchment.

Impervious fraction of contributing catchment (%)	Wetland surface area (at PWL) as a proportion of the total contributing catchment (%)
35	2.4
45	2.8
55	3.3
65	3.7
75	4.2
85	4.6
95	5.1

Imperviousness must be based on a conservative estimate of the finished development layout (which will need to be confirmed at detailed design) accounting for roads, roofs and general impervious land use.

For the purposes of allocating land for stormwater treatment, the surface area at PWL in Table 16 must be increased by 30% to account for batters and ancillary works to accommodate structures and maintenance access.

Where it is considered that the 30 per cent factor is not appropriate, or where Wellington Water decide that the topography requires additional certainty, the designer may be required to generate a conceptual earthworks model with the area defined for the PWL showing the batters to tie into the surrounding landform and provision for access. Full modelling of the wetland bathymetry is not required at the concept stage.

The proposed wetland footprint must be shown on scaled plans which clearly identify relative levels, wetland inlet location, outlet and discharge to receiving environment condition. Concept design reporting will need to provide information on the following;

- contributing catchment area and imperviousness assumptions
- upstream pipe network alignments
- ground conditions and any soils/groundwater testing
- description of defining levels (including further flood mitigation if included).

3.4.2.3 Wetland sizing at preliminary design

At preliminary design, the designer must resolve any outstanding uncertainty with the wetland footprint and or earthworks volumes based on refined sizing and earthworks modelling.

The water quality volume (WQV) must be accommodated in the wetland, below the PWL, as per the bathymetry requirements summarised in Table 17 below. The WQV is calculated as per Section 2.4.2. The WQV defines the footprint (area) of the wetland at the PWL through Equation 4 below (which incorporates an approximation of the varying bathymetry as per Table 17 i.e. shallow/deep water plant areas and open pool/forebay areas).

Equation 4: Calculation of wetland area at permanent water level.

$$A_{PWL} = \frac{WQV}{(0.8 \times 0.25 \times 0.85) + (0.2 \times 1.4)}$$

Where:

A_{PWL} = the wetland footprint at the top of the PWL (m^2)

WQV = calculated water quality volume based on Section 2.4.2 (m^3)

0.8 = proportion of wetland comprising shallow/deep water plant as per Table 17

0.25 = average depth (m) of shallow/deep water plant as per Table 17

0.85 = reduction factor to account for volume of plant mass within the shallow/deep water plant areas

0.2 = proportion of wetland comprising open pool and forebay as per Table 17

1.4 = average depth (m) of open pool/forebay areas (>0.5m in depth at PWL) as per Table 17

Table 17: Wetland bathymetry and depth relationships to be achieved.

Design calculation	Description
40% (±5%) PWL area between 0.00 and 0.25m deep at PWL	Shallow water plant areas provide habitat for selected vegetation to grow.
40% (±5%) PWL area between 0.25 and 0.50m deep at PWL	Deep water plant areas provide habitat for selected vegetation to grow.
10% (±5%) PWL area between 0.50 and 1.20m deep at PWL	Intermediate deep pools and outlet provide habitat diversity in the wetland.
10% (±5%) PWL area between 0.50 and 1.2-2.0m deep at PWL	Sediment forebay provides initial settlement of coarse sediments to protect wetland from smothering and support maintenance.
The length of the wetland must be at least 4 times the width at PWL	Elongated wetlands prevent the risk of short circuiting.
Batters below safety bench must be no steeper than 1V:4H	Batters below safety bench (starting at 0.25m below PWL)
At PWL a safety bench 2m wide must be provided at a maximum slope of 1V:8H	Safety bench must extend around entire perimeter immediately below PWL. The safety bench provides a gradual transition to reduce risk of unintended ingress and supports dense vegetation growth to exclude access.
Batters above PWL must be a maximum of 1V:4H	Batters above PWL to transition to existing ground. Batters can be steeper in exceptional circumstances with Wellington Water approval and appropriate safety/structural features such as gabions/fencing. Flat and variable batters are encouraged to support landscape and biodiversity outcomes.
Event detention depth (EDD) = 0.35m	The event detention volume must be engaged above the PWL with a maximum depth (EDD) of 0.35m to support robust plants.
Velocity of WQF with depth at: PWL + (EDD/ 3) At the WQF, the velocity should be less than 0.1m s^{-1}	The velocity of the water quality design flowrate (WQF), assuming a water level of 1/3 of the way between the PWL and EDL, must be less than 0.1ms-1 to avoid sediment resuspension and protect plants. The calculation must be based on the critical cross section i.e. smallest cross sectional area.

3.4.2.4 Earthworks model

Based on the area defined by Equation 4, an earthworks model must be produced using either 12d, Civil3D or another approved modelling package. This model must place the wetland within the post developed landform and define the banded bathymetry and features such as the forebay, intermediate pool and outlet pool as per Table 17. Figure 11 (next page) shows a kidney shaped layout with banded bathymetry.

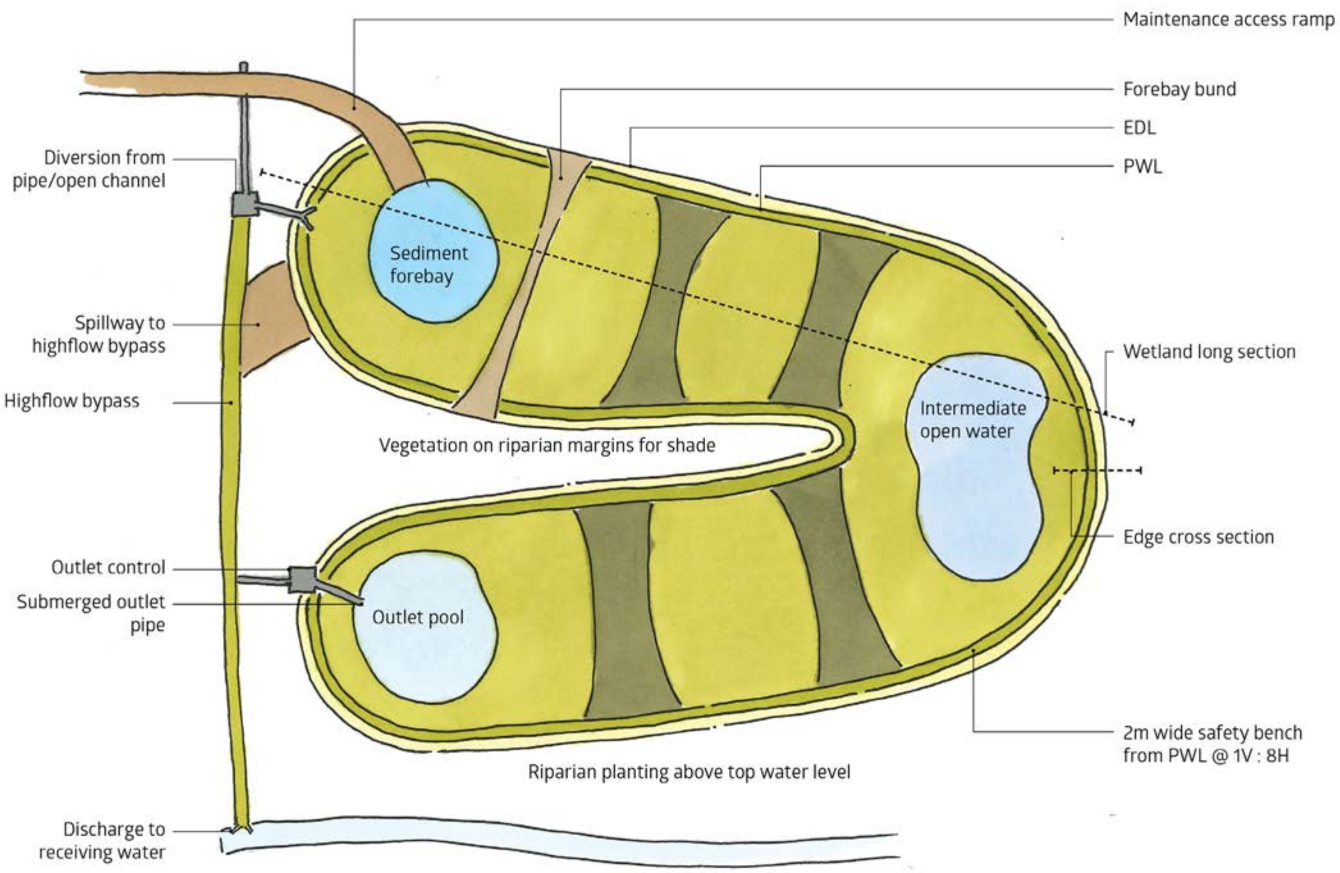


Figure 11: Schematic of a kidney shaped wetland.

Based on the earthworks model, a stage storage/area report must be generated to verify the proportion of the wetland within the required depth bands and ensure compliance with Table 17. This may require several iterations to get the final layout. Note: The final bathymetry must include a spread of depths across the range from 0–500mm below the PWL, rather than large areas dominated by the upper bounds of the shallow and deep water plant ranges.

3.4.3 Component design

This section provides guidance on the design of the individual components of a constructed wetland.

3.4.3.1 Wetland bathymetry

The design of constructed wetlands must provide the required level of treatment while being resilient to flow dynamics (velocities, inundation frequency and duration of inundation). This is achieved through designing the internal bathymetry of the wetland to manage flow paths, depths and subsequently velocities. The design of the internal wetland bathymetry is therefore fundamental to the treatment performance and long-term resilience of any stormwater treatment wetland to:

- support robust vegetation communities
- prevent excessive velocities contributing to scour, re-suspension of sediments and/or stripping of important algal growth from the stems of plants.

Typically, stormwater treatment wetlands are designed based on a banded bathymetry whereby the wetland profile in the long section comprises a variable level with alternating deep and shallow water plant sections interspersed, with occasional open water ponded areas. The cross section, perpendicular to the flow direction, at any point is uniform with water spread evenly across the full width of the wetland.

The hydraulic efficiency is optimised through designing the wetland to maximise the length to width ratio:

- within the constraints of the velocity requirements and topography
- ensuring that flows engage the full width of the wetland.

Where the site allows, hydraulic efficiency is achieved with elongated systems that are designed with smooth bends and impermeable bunds. This design helps to achieve a layout that supports the banded bathymetry along the sinuous extended flow path. The final layout of the wetland must therefore consider a range of factors including topography; earthworks volume; implications of large embankments; slope stability and landscape fit. Figure 12 (below) shows a long section through the kidney shaped wetland example shown in Figure 11.

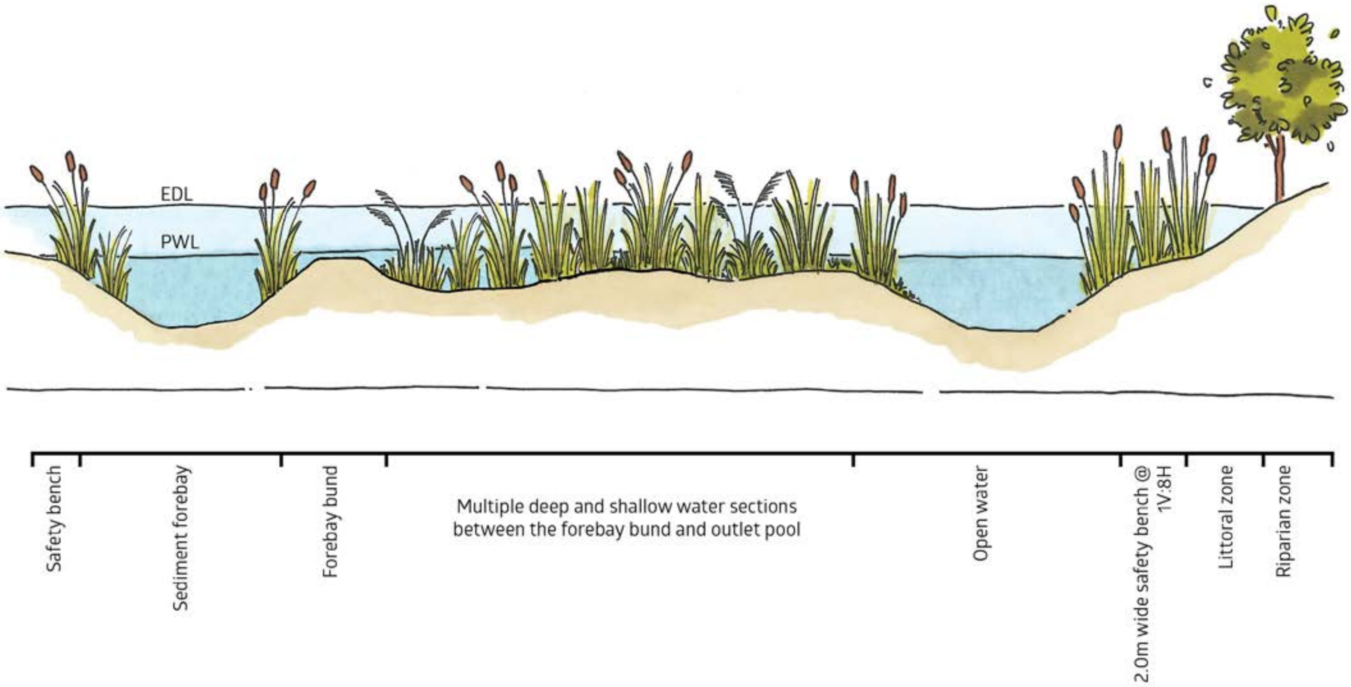


Figure 12: Long-section through kidney shaped constructed wetland example in Figure 11.

Figure 13 below shows an edge section through the kidney shaped wetland example shown in Figure 11.

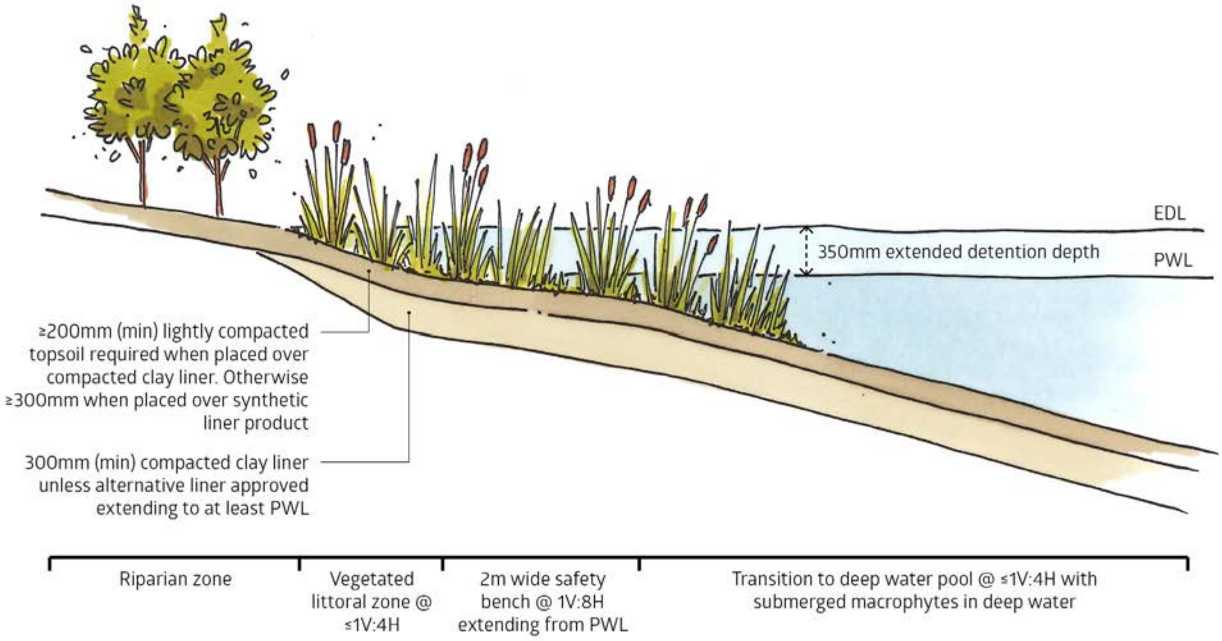


Figure 13: Edge section through the kidney shaped wetland example shown in Figure 11.

3.4.3.2 Wetland inlets and diversions

The design of inlets is critical for wetlands to ensure that the appropriate flow can be passed through the system without excessive velocities/flowrates causing damage. Table 18 below provides requirements for key elements of inlets and methods of verification to demonstrate compliance.

Table 18: Wetland inlet design requirements.

Parameter	Requirement	Verification method
Inlet pipe	The inlet pipe must comply with the Regional Standard for Water Services and be appropriately sized for design flows.	Approval at time of detailed design sign off. All pipe sizes to be clearly marked on as-built drawing set. Note this guideline does not cover design of upstream reticulated networks.
Diversion configurations	Any diversion works (including chambers, weirs, orifices and energy dissipators) must be appropriately designed for the target inflows with consideration for operating hydraulics, avoidance of upstream flooding, operating head and site constraints. Tolerances for critical structures must be stated in construction specifications.	Approval at time of detailed design sign off. As built verification survey of all critical levels required to ensure diversion will function as intended. Any site- specific maintenance requirements must be documented in operations and maintenance plan.
Erosion protection	Design of inlets must consider potential for erosion for all design inflows.	Approval at time of detailed design sign off supported by appropriate calculations.
Construction tolerances	Construction tolerance for the inlet is 25mm.	As-built survey.

Energy dissipators associated with inlets should aim to reduce water velocity, prevent erosion of areas surrounding the inlet, and reduce resuspension of accumulated sediments within the forebay. Further details on energy dissipation design are provided in Auckland Council's technical report, TR 2013/0183. Gross pollutant traps and debris screens can be included as part of the inlet design where wetlands are located in catchments with particularly high litter loads such as treatment of commercial/industrial areas.

In instances where topography and constraints do not support a single inlet, wetlands can incorporate multiple stormwater inlets, provided:

- all flows into the wetland are subject to pre-treatment (eg a forebay)
- there is enough calculated treatment area between each inflow and the final outlet structure.

Instances where multiple inlets are required must be approved by Wellington Water's Land Development Team at concept design.

3.4.3.3 Inlet design

Inlets must be designed based on the water quality design flowrates (WQF) as per Section 2.4.3. This defines the target rate to be discharged into the wetland forebay with flows exceeding this to bypass the wetland via the high flow bypass.

Careful consideration must be given to the invert levels within the upstream reticulated network. This includes ensuring that the wetland operation does not result in backwatering, which could cause capacity restrictions or surface flooding in the upstream catchment (due to either head at the point of diversion or the water surface at the top of the operating water level in the wetland).

The design of inlet and diversion structures must consider:

- erosion/scour
- sediment deposition and the risk of blockages
- safe access for routine/emergency maintenance
- public safety.

Wetland inlets can include a range of configurations including:

1. **Side cast weir in channel/manhole (flows controlled by head levels)**

   Design of weirs within network (either pipe or channel) to preferentially divert water quality flows into the wetland forebay. The head developed by the flowrate will subsequently engage a broader bypass weir with flood flows able to bypass. This arrangement is well suited to larger systems where flowrates will be large. Figure 14 below shows this arrangement with diversion into the forebay at the right and the high flow bypass to the left.

Figure 14: Photo of inlet weir with water quality flow discharged to forebay (top of frame).

2. **Throttled bifurcation in manhole**

   Design of pipe connection to wetland forebay, which sits below the invert level of the reticulated network. In this instance, the diversion pipe is sized to throttle the flows to the WQF when flowing at full capacity. When the flowrate is exceeded, the bypass flows continue within the network to the high flow bypass. Care must be taken to ensure that any bifurcation does not result in blockages or snag points, with internal trowelled haunching typically used to direct flows efficiently into the bypass.

3. **Feedback with wetland water levels backwatering to diversion point**

   Where levels suit, large systems may be designed with simple feedback, where flows initially flow into the wetland until the EDV is fully engaged, at which point the water level translates to the diversion point and enables bypass of ongoing flows. Careful consideration must be given to potential velocities within the wetland and ensuring that following engagement of the bypass, excessive flows are not able to continue into the wetland. This configuration is typically only suitable on flat sites where velocities are low and there is insufficient fall to support weirs and so on.

4. **Pumped flows**

   In some instances, pumps may be used to get flows from deep reticulated networks into wetlands. This will typically only occur in retrofit situations in built up areas (such as Waitangi Park in Wellington) or where the wetland is designed as part of a stormwater harvesting scheme. Where pumps are included, this must be discussed with Wellington Water at concept design and implications for lifecycle operations and maintenance well understood. Typically, these systems will not be subject to high flow rates (due to pump limitations) and will operate without any EDV as flow through systems. Flow through systems are not specifically covered in this guideline and should be discussed with Wellington Water to determine a hydraulic residence time (HRT) suited to the catchment specific contaminants and receiving environment.

Fish passage

Fish passage must be provided through the wetland inlet/outlet:

- in any instance where wetlands will pass a permanent baseflow from undeveloped upstream catchments (such as where perennial streams discharge into the reticulated network upstream of the diversion point)
- where upstream viable habitat exists.

This fish passage will need to consider the likely range of species suited to the upstream habitat and their migratory requirements. In the Wellington region, this will typically include designing to support climbing species.

Note: Fish passage need not be provided for all flow regimes with a preference for baseflow conditions only. The inclusion of fish passage must not be based on the presence (or otherwise) of species in the upstream catchment or the incidence of other barriers above or below the wetland. However, fish passage must provide potential for fish to migrate in the future, should these impediments be removed.

Improved fish habitat may be achieved by:

- including structure(s) within the wetland (eg large woody debris in transverse deep pools)
- shading open pools (eg by routing boardwalks over open water to provide shade).

Fish passage should only be mandated where wetlands are hydraulically connected with an existing waterway, with upstream habitat that can support native freshwater species. The inclusion of fish passage should be considered on a case by case basis, with design based on other industry guidance.

3.4.3.4 Sediment forebay

A sediment forebay should be provided in all wetland designs to capture the coarse fraction of sediments and prevent the main body of the wetland from being smothered. Table 19 below gives the design parameters for the sediment forebay.

Table 19: Sediment forebay design parameters.

Requirement	Description
Area of Sediment forebay = 10% x PWL area (±5%)	The area of the forebay(s) needs to be in proportion to the area of the wetland at the PWL to provide sufficient storage for coarse sediments. If there are multiple forebays (only permitted with Wellington Water approval), the total forebay area should comply with this requirement.
Maximum depth of Sediment forebay = 2 m	The forebay needs to be maintainable. Depths over 2m can result in special equipment being required for maintenance and potential issues with anaerobic conditions.

Requirement	Description
A length-to-width ratio of between 1:1 – 2:1	The forebay is the part of the wetland designed to retain coarse sediment and other debris before water enters the rest of the wetland. A suitable length to width ratio is required to allow course sediment to settle whilst avoiding excessive settlement of very fine particles.
At PWL a safety bench 2m wide must be provided at a maximum slope of 1V:8H	Unless fenced, the forebay must include a 2m wide safety bench around the outside perimeter immediately below PWL.
Maintenance access track	Where it is proposed that cleanout must be by an excavator within the forebay, a maintenance access track must be defined from the top of batter to the base of the forebay. This track must be 4m wide with a maximum grade of 1V:8H. This track must be stabilised with compacted basecourse but may be planted to mask visual impact. The track must not be planted in large shrubs or trees and must be clearly marked on the operations and maintenance plan for the site.
Maintenance bench within 12m of any part of forebay area	Where it is proposed that the forebay will be maintained from the perimeter, all parts of the forebay must be within 12m of an access bench to ensure the forebay can be dug out without the use of special equipment. For larger systems, this will require stabilised vehicle access to the base of the forebay.
Maintenance bench should be a minimum of 2.5m wide and maximum of (1V:8H slope) at PWL	A 2.5m wide bench suitable for dry weather use by excavator above PWL, where access into forebay base is not required.
Batters below safety bench maximum 1V:3H	The forebay must have flatter batters below the safety bench to avoid unintended ingress.
Batters above PWL maximum 1V:4H	Batters above PWL to transition to existing ground. Batters can be steeper in exceptional circumstances, with Wellington Water approval, and appropriate safety/structural features such as gabions/fencing. Flat and variable batters are encouraged to support landscape and biodiversity outcomes.

Sediment forebay operational considerations

Pre-treatment via the sediment forebay is key to promoting wetland longevity, retaining coarse to medium-sized fractions of suspended solids, supporting practical maintenance and preventing smothering of the wetland treatment area. Finer sediments and dissolved contaminants are preferentially passed to the macrophyte zone for removal.

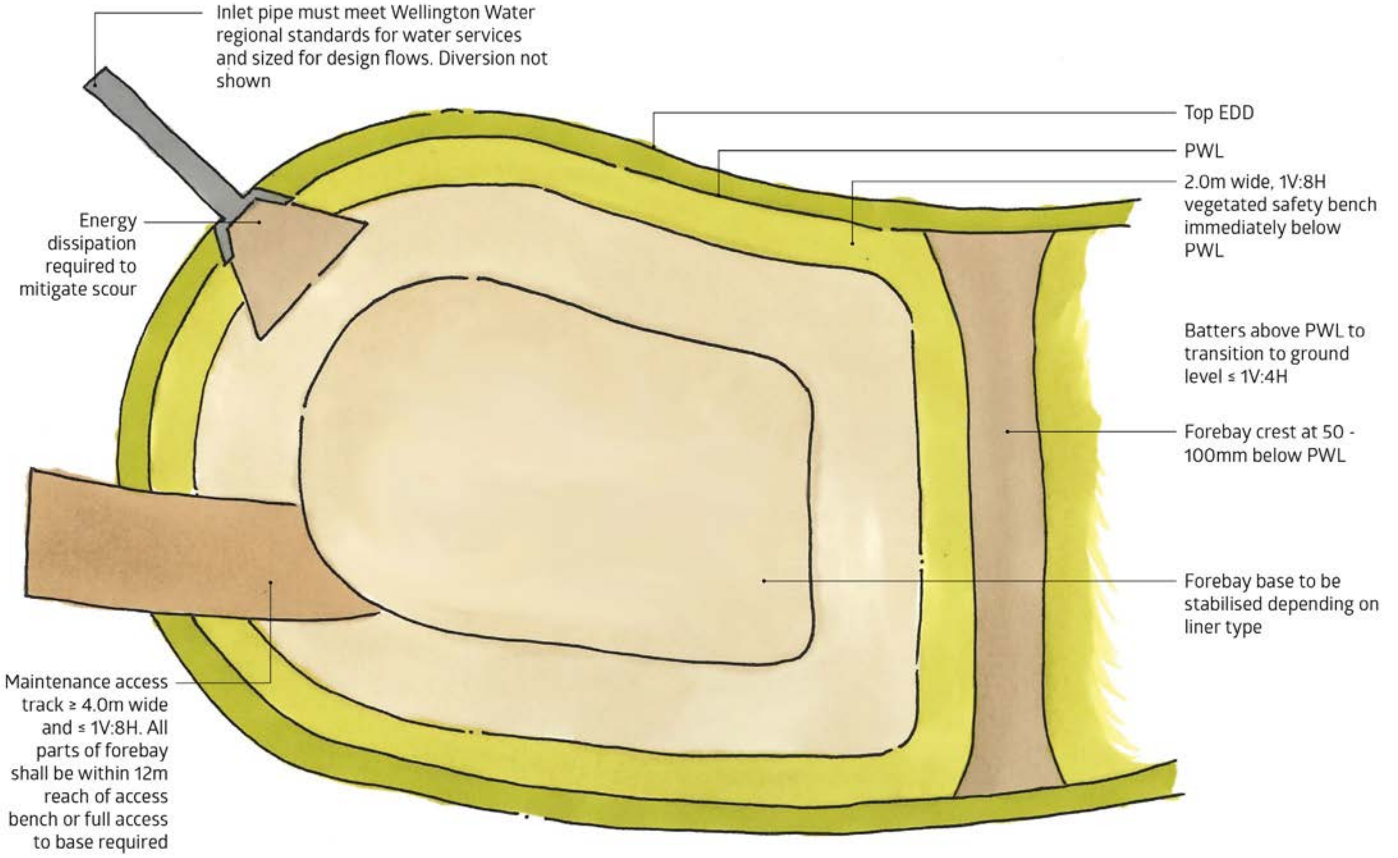
During rainfall events, a well-designed forebay will initially operate in a displacement mode, with cleaner stored water being displaced by untreated influent stormwater. Once the rainfall volume exceeds that stored in the forebay, sediment removal is by physical settlement and therefore requires low velocities. It is important that stormwater inflows do not cause re-suspension of accumulated sediments; so, it is also important to include a high flow bypass to reduce the risks of re-suspension in the forebay from peak flows during infrequent storm events.

With the forebay capturing the largest sediment load from a stabilised catchment, maintenance access to allow for periodic sediment removal is an important design component. A well-designed maintenance access track (or perimeter access bench for smaller systems) must be included and consideration given to truck access for removal of accumulated sediments.

Where the forebay is formed in compacted clay, the base of the forebay must be lined with a minimum 300mm thick compacted crushed rock (base-course) to enable excavator operators to differentiate between accumulated sediment and the forebay base. In any instances where wetlands are constructed with synthetic liners, the forebay must be lined with a 300mm thick layer of site concrete for added precaution, unless clean out will be via a vacuum truck or working entirely from the perimeter maintenance bench. Figure 15 provides an image of a typical wetland forebay.

Figure 15: Wetland forebay with maintenance access left of inlet pipes.

The forebay must be separated from the main wetland body with an impermeable bund constructed with compacted earth fill and a level 200mm wide concrete level spreader at 50-100mm below PWL. This must disperse flows across the full width of the wetland and avoid the propagation of preferential flow paths. The level spreader enables this function to be maintained in the long term and will support periodic maintenance access for the removal of accumulated gross pollutants such as floatable litter. The bund must be well vegetated on the upstream and downstream faces. The layout requirements for a typical forebay and forebay bund are shown in Figure 16.


Inlet pipe must meet Wellington Water regional standards for water services and sized for design flows. Diversion not shown

Energy dissipation required to mitigate scour

2.0m wide, 1V:8H vegetated safety bench immediately below PWL

Batters above PWL to transition to ground level ≤ 1V:4H

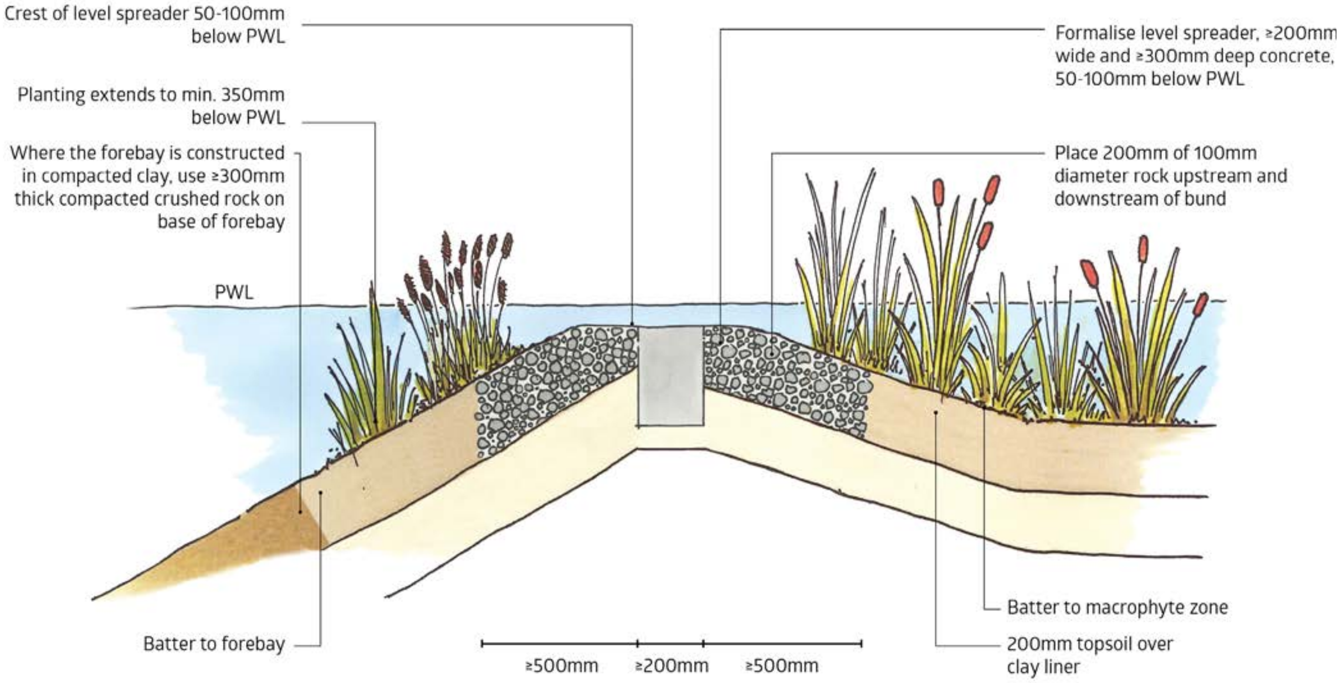
Forebay crest at 50 - 100mm below PWL

Forebay base to be stabilised depending on liner type

Maintenance access track ≥ 4.0m wide and ≤ 1V:8H. All parts of forebay shall be within 12m reach of access bench or full access to base required

Figure 16: Forebay layout requirements.

Figure 17 shows a typical forebay bund with concrete level spreader.


Crest of level spreader 50-100mm below PWL

Planting extends to min. 350mm below PWL

Where the forebay is constructed in compacted clay, use ≥300mm thick compacted crushed rock on base of forebay

Formalise level spreader, ≥200mm wide and ≥300mm deep concrete, 50-100mm below PWL

Place 200mm of 100mm diameter rock upstream and downstream of bund

Figure 17: Typical forebay bund.

3.4.3.5 Wetland outlet

The design of the wetland outlet controls the treatment function of the wetland:

- by enabling the EDV to be engaged dependent on the inflows
- controlling the EDV draw down over an average of 24 hours to support the mix of treatment pathways.

The design of the outlet must also ensure that the wetland will be resilient to a range of flow conditions and be maintainable without unacceptable risk of blockage. As the outlet defines the PWL in the wetland, it must also be designed to enable periodic drawdown of the water surface and reduced levels during plant establishment. The connection between the outlet control and the wetland should be submerged to pass cooler water to the receiving environment and reduce the risk of discharging floating debris/litter which can cause blockages.

Table 20 provides requirements for key elements of outlets and methods of verification to demonstrate compliance.

Table 20: Wetland outlet design requirements.

Parameter	Requirement	Verification method
Outlet hydraulics	Control outflows to pass design flows in wetlands and support drawdown of event detention over average of 24 hour period.	Stage storage and stage outflow calculations to demonstrate hydraulic function.
Outlet pool	Include an unplanted deep pool (1.2–1.5m deep) at the downstream end of the wetland. Treated flows to be drawn from at least 500mm below the surface via a pipe connection to the outlet control structure.	Earthworks model based on finished surface. As-built survey to verify finished levels.
Outlet structure	Hydraulic control to be contained within a suitable manhole or open chamber with flow control to define PWL and drawdown of event flows.	Design plans and as-built survey showing all critical levels within tight (5mm) tolerance.
Outlet location	Outlet control structures must be accessible on foot for all weather inspection and maintenance (ie within manhole on batters) and must not be positioned within the wetland itself where access is limited.	Design plans and as constructed drawings showing all critical levels within 25mm tolerance.
Fish passage	Where wetlands are located connected to perennial streams (with fish passage required) the design must include provision for passage in a range of typical operating events. Fish passage will not be achievable across the full range of operating conditions while also achieving detention requirements.	Design plans and as constructed drawings.
Discharge to receiving environment	All outfalls must comply with Regional Standard for Water Services to avoid scour and instability. Discharge can be either to reticulated pipe network or natural/ constructed watercourse	Design plans and as constructed drawings .
Construction tolerances	Construction tolerance for the outlet is 25mm.	As-built survey.

3.4.3.6 Outlet structure

The outlet structure plays a critical role in wetland functioning as it controls the overall water volume and hydraulic regime within the wetland at normal operating depth and during higher flow events. The outlet structure therefore controls both water quality and quantity functions, and these requirements can be incorporated into a wide range of outlet structures. These can include (among others):

- slotted weirs in fixed weir plates
- perforated risers within manhole
- custom weir plates with graduated orifice openings.

Outlet design is critical to the long-term success and functionality of the wetland, as water depth affects wetland vegetation and subsequently treatment.

- Outlets must be sized and configured to achieve an average drawdown of the EDV over 24 hours.
- Calculation of drawdown must be based on appropriate weir formulas and accurate stage storage relationships based on approved 12d or Civil 3D earthworks design package. This calculation must demonstrate an average drawdown time of 24 hours over the full range of depths by calculating the drawdown of 24 hours at the mid-level of the EDD.

A submerged pipe outlet will:

- draw off water from cooler, deeper waters within the outlet pool
- reduce downstream effects associated with discharge of elevated surface water temperatures that can occur in wetlands during warmer summer months.

Subsurface outlet structures also:

- have the advantage of less frequent clogging as floating debris is not trapped in the outlet
- support easy maintenance with the hydraulic control situated in a structure on the wetland batter.

The hydraulic control should (where feasible) comprise an oversized concrete weir with a customised weir plate fitted within an accessible manhole. The weir plate should be designed to be adjustable (ie able to be raised/lowered) and removable when operational circumstances require modifications to be made following commissioning. This is particularly the case with wetlands subject to persistent base flow which may cause prolonged periods with water above the intended PWL based on originally calculated catchment hydrology.

Where possible, outlet structures should integrate features to allow for water drawdown for management and maintenance purposes; and provide control of the normal water level within the wetland. Water depth control is especially important during plant establishment; if it is too deep, the plants may dislodge or be drowned before they establish. Figure 18 shows a weir plate within an outlet control manhole with provision for replacement/re-cutting in the instance that performance is not in-line with intent.

Figure 18: Outlet from wetland with weir plate controlling drawdown flowrate and operating water level.

Outlet design calculations

Refer to Auckland Councils TR2013/018 Hydraulic energy management: inlet and outlet design for treatment devices for details on a range of calculation methods for different outlet configurations. These calculations can be used to calculate the drawdown rate within the wetland based on the mid-point of EDD water level to achieve the required 24 hour drawdown.

High flow bypass and spillway

The high flow bypass is to be designed to divert flows away from the wetland which exceed the storage for the EDV or the WQF calculated as per 2.4.3. Flows to the high flow bypass are controlled by the inlet diversion structure (3.4.3.2). Bypass flows are then routed around the wetland to protect it from potential scour and biofilm stripping from increased velocities.

- Where flood attenuation is included, the high flow bypass should incorporate flow controls to enable the flood storage to be engaged whilst still providing protection during the intermediate events. For example, throttle downstream of diversion with backwater engaging surcharge spillway back into wetland. The main wetland body and forebay can provide storage in the flood storage zone during these events.
- Where flood attenuation is required, a dedicated flood model of the wetland will need to be developed to design the flood storage zone and the high flow bypass.

- Where flood attenuation isn't included, the high flow bypass must be designed to have capacity for the 1% AEP event (or greater if required by the Regional Standard for Water Services). Where the wetland is diverting flows from a reticulated network and is not subject to overland flows this will be defined by the maximum pipe flow rather than the full 1% AEP discharge. Regional Standard for Water Services must be referred to for sizing of high flow bypass channels or pipe.

Table 21 shows design requirements for the wetland bypass and the verification methods to support it.

Table 21: Wetland high flow bypass requirements.

Parameter	Requirement	Verification method
High flow bypass	Wetlands must be constructed off line to flows in exceedance of the target water quality flowrate. The bypass must be designed to convey flows up to the 1% AEP plus climate change event (or greater if required by the Regional Standard for Water Services).	Design drawings and hydraulic calculations for all diversion structures and weirs.
Overflow spillways	Design should include provision for overflow spillways to be engaged at top of event detention or flood storage. Spillways should be located as close to inlet as possible and be sized to pass maximum flows without excessive head. Overflow spillways must be designed to withstand scour forces.	Design drawings and hydraulic calculations for all diversion structures and weirs.
Flood flow protection	Where wetlands are located online to large overland flood flows (including those engaged as part of flood attenuation) the design must consider potential risks in these infrequent events. Flood flow protection must demonstrate consideration of all flows up to 1% AEP event (or greater if required by the Regional Standard for Water Services) including climate change and include suitable spillways or throttled outlets with attenuation storage as part of design.	Design drawings and hydraulic calculations for all diversion structures and weirs.
Construction tolerances	Construction tolerance for the high flow bypass is 25mm.	As-built survey.

For events too large to be conveyed through the bypass (or when prolonged inflows exceed the design event detention volume), an emergency spillway should be included to convey at least the peak inflow from the 1% AEP event (or greater if require by the Regional Standard for Water Services) through the wetland. Spillways should, where practical, be located close to the inlet to reduce the risk of high velocity flows across the vegetated zones.

Spillway design considerations include:

- spillway scour protection
- downstream conveyance capacity constraints
- the downstream receiving environment, in terms of potential for property damage and safety risk due to spillway discharges
- safety considerations detailed in dam regulations
- geotechnical stability
- wetland embankment settlement.

The emergency spillway is usually designed as a trapezoidal channel, which consists of a channel cut in the side of the wetland embankment extending to the discharge location. All spillway design must comply with the Regional Standard for Water Services.

3.4.3.7 Flood storage volume

The flood storage volume is (FSV) engaged when the wetland is required to provide attenuation of infrequent large events with controlled drawdown, to reduce the risk of downstream flooding. This is achieved by passing the required flow within the bypass, with site specific hydraulic control creating backwater and surcharge into the wetland to engage the attenuation. The maximum flood storage level (FSL) will be:

- defined by the perimeter ground levels or bunds
- demonstrated to contain the peak water level in the largest flood design event, based on standard modelling software approved by Wellington Water.

Flood modelling or the tools to support it are not covered in this guideline. The wetland design must ensure that the FSV contains the full designated flood volume (allowing for climate change) and that it does not spill away into neighbouring properties with an acceptable level of freeboard.

3.4.3.8 Maintenance access

Maintenance access requirements are as follows:

- Maintenance access must be provided to the access benches around the sediment forebay and the main wetland body.
- The access way must meet the Regional Standard for Water Services requirements of a track at least 4m wide and no steeper than 1V:5H and suitable for use by trucks.
- There must also be room for machinery to work at the inlets and outlets.
- The access must provide dry weather maintenance access to the forebay and key hydraulic structures.
- All weather access must be provided to any structures where blockage could result in flooding to property.
- The access must be in public land or protected by an easement.

Table 22 below provides requirements for maintenance access and methods of verification to demonstrate compliance.

Table 22: Maintenance access design requirements.

Parameter	Requirement	Verification method
Forebay access	Full trafficable access (crushed gravel or similar) must be provided to hardstand for small systems (where standard long reach excavator can access all areas of forebay from hardstand) or 4.0m wide access track to base of forebay for larger wetland. Access track to be no steeper than 1V:8H and be constructed with 150mm cement treated crushed rock.	Sign off as part of maintenance plan before construction approval.
Wetland vehicular access	Vehicle access (ute) should be provided to all hydraulic structures (inlets/outlets). Design of access track must consider other site users and public safety but can comprise pedestrian path with allowance for maintenance closures. All weather access must be provided to any structures where blockage could result in flooding to property.	Sign off as part of maintenance plan before construction approval.
Wetland pedestrian access	Pedestrian access must be provided around the entire perimeter including any bunds, structures or hydraulic controls. Preferred access routes should be marked on maintenance plans and maintained free of excessive vegetation growth.	Sign off as part of maintenance plan before construction approval.

Maintenance access layout

The layout of the wetland must include access for maintenance purposes. While machinery can readily access all areas of small wetlands from the banks of the wetland, maintenance access for larger wetlands can be included in the wetland design by incorporating structural elements into bunds to support vehicles.

Good access is essential in key areas where maintenance is required on a more regular basis, such as areas with litter screens or gross pollutant traps; the inlet, wetland forebay or other pre-treatment areas; and wetland outlet structures. Routine maintenance of these areas would include removal of gross pollutants and plant litter from screens; inspections of inlets and outlets; and monitoring of sediment levels within the pre-treatment devices. Areas within the main body of the wetland require less formalised operational access due to the infrequent maintenance requirements following establishment.

Pedestrian access is required for vegetated areas of the wetland, including buffer margins, to allow for weed control and maintenance of vegetated areas.

3.4.3.9 Wetland liner

Design requirements for the wetland liner are given in Table 23.

Table 23: Wetland liner design requirements.

Parameter	Requirement	Verification method
Permeability	Entire wetland (to top of PWL min) must demonstrate a permeability of $1x10^{-8}$ $m.s^{-1}$ or lower.	Geotechnical testing at time of construction or approval of synthetic liner prior to installation
Natural clay liner option	Minimum 300mm of well compacted clay required across entire wetland. The use of in-situ clay requires specific geotechnical advice and the approval of Wellington Water.	In-situ and imported clays must demonstrate suitable compaction to achieve required permeability to at least 300mm. Minimum testing requirements of 1 test/50m^3 compacted clay material (based on 300mm uniform liner depth) to be tested by independent soils laboratory in accordance A triaxial constant head permeability test (eg ASTM D5084–03 Method A, or BS 1377:1990 Part 6) is recommended.
Synthetic liners	Geosynthetic Clay liners (GCL) may be suitable in absence of suitable clay source. Approval for material to be provided before specification including manufacturers testing and independently verified performance data. All liners must meet the appropriate Geosynthetic Institute specification, eg GCL3 for Geosynthetic Clay liners. Consideration must be given to slope stability on batters to prevent sloughing.	Material to be pre-approved. Installation must be undertaken by approved installer with comprehensive quality assurance procedures to verify integrity of all joins, welds, protrusions and anchoring. Protection of liner post installation critical during subsequent works.

Design requirements for the wetland liner are illustrated in Figure 19.

Figure 19: Installation of Geosynthetic Clay liner with bedding sand beneath and topsoil over.

Where an imported impermeable liner is not proposed, the suitability of the in-situ soils must be investigated to establish the permeability of the soils.

- The permeability of in-situ soils must be confirmed by an approved soils laboratory based on samples collected at multiple locations across the base at locations specified by the design engineer.
- In the instance that in-situ materials are shown to exceed the permeability requirements and are homogeneous across the entire floor of the wetland, approval may be sought to trim and proof roll the in-situ material rather than reworking it.
- In all instances, the entire batter from the wetland base to at least the PWL must be reconstructed with an approved 300mm thick (perpendicular to batter slope) liner to ensure that no inconsistencies result in water losses.

Where imported clay material is required, earthworks must allow for the 300mm clay liner and testing must verify the consistency and compaction of the installed liner. All imported clay liner material must be tested and approved prior to delivery to site.

Testing of site or imported clay material will define the permeability based on target compaction limits (95% of maximum dry density). Compaction in the prepared wetland base and batters must then be verified to at least the full depth of lining (300mm).

Design requirements for three different wetland liner scenarios are illustrated in Figure 20 to Figure 22 below.

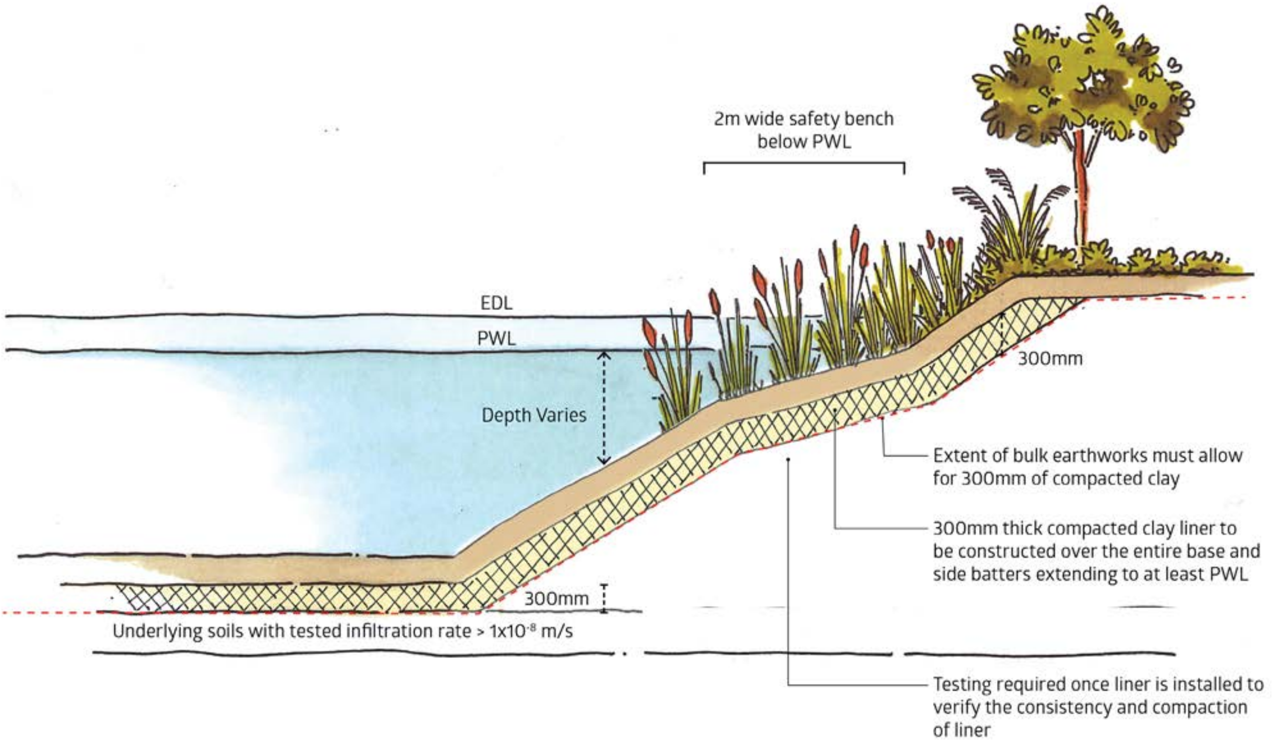


Figure 20: Wetland liner construction in permeable soils (coastal sands).

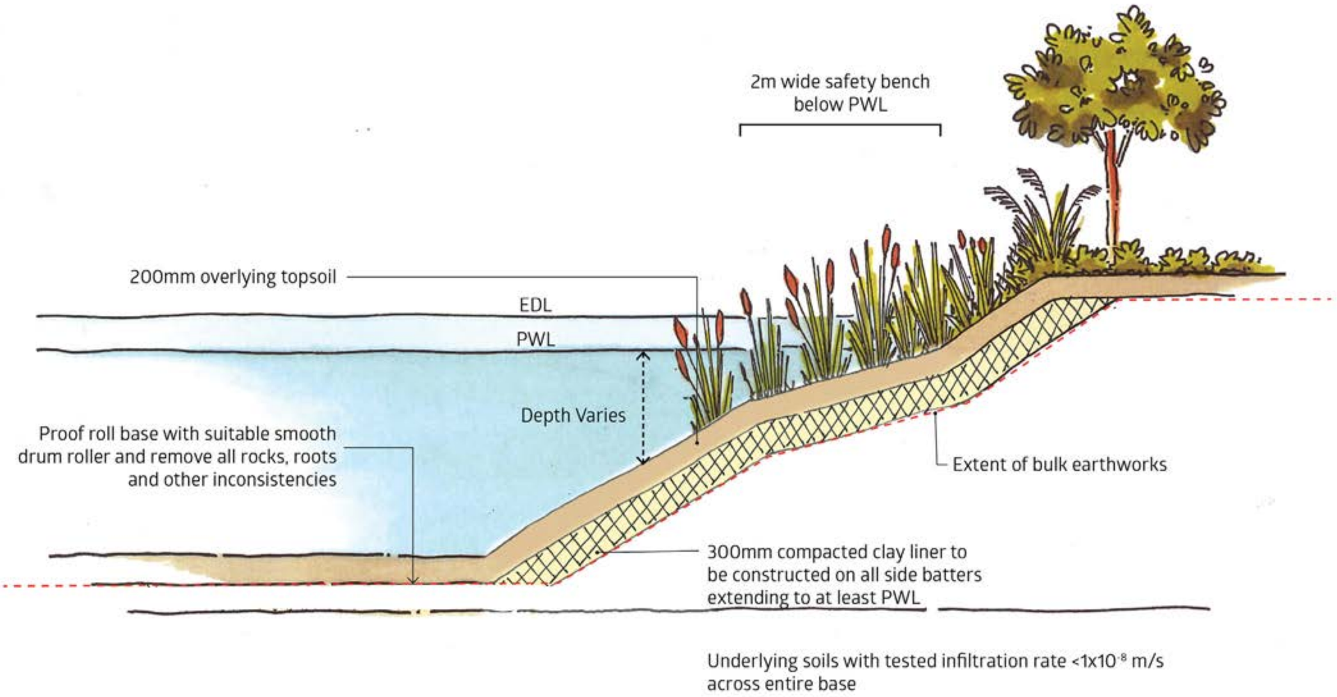


Figure 21: Wetland construction in clay soils.

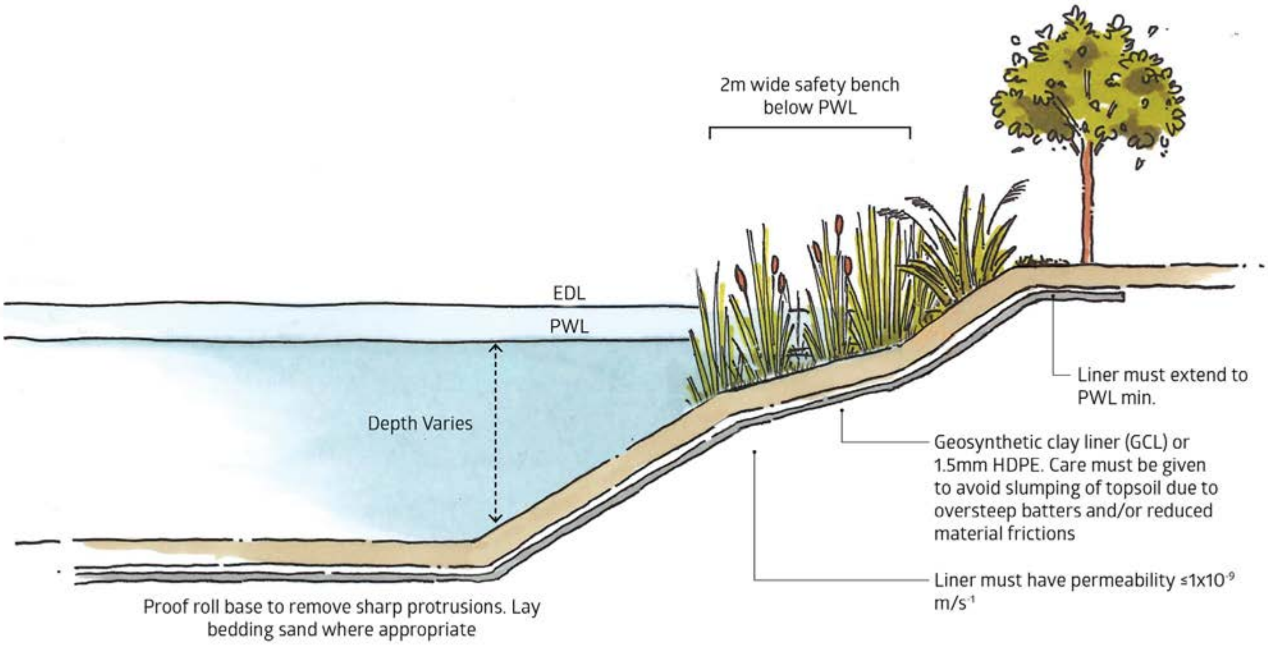


Figure 22: Synthetic liners.

3.4.3.10 Bed materials

Wetland substrates and bed materials are important structural and water quality treatment components, supporting healthy vegetation growth, providing a treatment medium and controlling the coverage of vegetation. Typically, standard commercial topsoil without added compost or fertilisers provide a good medium. The topsoil should be not too high in clay or peat to enable the substrate to remain reasonably friable in saturated conditions.

In many instances site sourced topsoil will be suitable to be used as long as it is free of vegetation, roots/seeds of invasive weeds or excessive clay. Where site sourced topsoil is to be reused, the surface vegetation must be stripped and disposed offsite; and the topsoil must be:

- stripped to verified depth of suitable quality soils
- stockpiled during works
- placed into the wetland following bulk earthworks and lining or sand
- applied to a depth of 200mm minimum.

Site sourced topsoil is more suited to be placed below the PWL as any residual terrestrial weed seeds will not survive in saturated conditions. Where topsoil above the PWL is not sterilised imported topsoil, additional resources will need to be put into the weed management during the initial establishment phase.

Wetland topsoil must have a minimum depth of 200mm (measured when lightly compacted) and be 300 mm when placed over any synthetic liner product.

Areas of the wetland where plant growth is not desirable (such as the outlet pool and open water pools where submerged plants are not encouraged) must be covered in washed gravels or basecourse. When placed over synthetic liners care must be taken to avoid any sharp rocks penetrating the liner.

Figure 23 shows planting underway into the wetland substrate.

Figure 23: Planting into substrate (topsoil stripped from site and laid over GCL liner).

Figure 24 shows a recently planted wetland with an elevated water level.

Figure 24: Wetland following planting with water level raised.

3.4.3.11 Planting

Selection of suitable plants for wetlands is critical to ensure sustained performance under a range of conditions. Designers must select species adaptable to the broadest ranges of depth, frequency and duration of inundation.

Plant specifications

The following specifications are required:

- Plants must be supplied as individual plants (ie minimum 0.5 L pots) and must not be substituted for manually separated reclaimed clumps or propagation trays cut into units. Plants must be healthy and robust with vegetation extending above the planted water depth.
- Plants should be planted with a minimum density of four plants/m^2 to form full coverage of the shallow and deep water plant areas. Water levels should not overtop planted vegetation during the developmental growth phase. Water levels can be raised as the plants become well established (two to three months when planted in spring). Up to 10% of plants can be diversity planting (ie not purely selected for treatment characteristics) to increase overall biodiversity, particularly around the perimeter of the wetland.

Planting and plant selection

Consider the following when planting and selecting plants:

- Tall perennial species should be planted in preference to non-perennial species. Raupo should not be planted due to die-back in winter and tendency to promote preferential flow paths.
- A diverse group of plants should be planted. Native local species (with seed eco sourced by nurseries) should be used, to represent local vegetative communities and ensure plants are well adapted to local conditions.
- Vegetation should be limited to plants whose root structure will not cause damage to the wetland liner or compromise the structural integrity of any bunds.
- Dense, rigid and tall water plant species should be selected as far as practical within deep water plant zones. Tall water plant species with spreading aerial cover should be selected next to open water areas.
- Vegetation that provides a high level of shading (including trees, shrubs and reeds/tall sedges) should be planted around and within the wetted margin of the wetland.
- Tall species with spreading crowns provide aerial cover, especially if located on the northern aspect of a wetland, which helps to reduce elevated temperatures in exposed water bodies.
- Shade-tolerant herbaceous water plant vegetation should be selected for shaded areas.
- Care must be taken where synthetic liners are used in areas with permeable in-situ soils. In these instances, the use of large tree species should be avoided due to potential instability and risks of damage to synthetic liners.

Planting of a constructed wetland is shown in Figure 25.

Figure 25: Planting of completed wetland with water level lowered.

Wetland species

The selection of species to be planted in constructed wetlands must consider:

- The important treatment functions within the wetlands and ensure that species are compatible with the biological and physical conditions in the system. This differs from natural wetlands, which are typically subject to reasonably good water quality and water clarity; and do not necessarily provide the maximum water quality improvements within their footprints.
- Opportunities to include species that may be valued locally as resources. These could include Harakeke (Phormium tenax), Kuta (Eleocharis spacelata), Kāpūngāwhā (Shoenoplectus tabernaemontani) or local Rongoā species.

Plant lists

The plant lists in Table 24 include only those to be incorporated into the functional zones within the wetland. This does not include the perimeter terrestrial planting, where the landscape integration and other aspirations for the site should be considered.

Shrubs and trees have been excluded from the lists. Shrubs and trees will typically be planted above the littoral zone and should consider the local site context and ensure that species are well suited to the conditions. Note that Raupo (Typha orientalis) has been excluded. Raupo is typically avoided within treatment wetlands as it:

- tends to over dominate other species and grow in a way that creates preferential flow paths and reduced treatment
- produces large amounts of organic material (dead leaves); and can result in nutrient loads within the wetland itself and support conditions for mosquito breeding.

The plant lists include recommended species for the respective planting zones. These species are well suited to the local Wellington conditions and the physical conditions within typical constructed wetland systems. Where specific projects require site specific considerations (such as with saline ingress), other species may be suited as well. Advice must be sought from a suitably experienced professional for the preparation of wetland planting plans.

Table 24: Constructed wetland plant lists.

Planting zone and description	Plants
Shallow water plants – Aquatic macrophytes Planting zone from PWL to maximum 250mm below PWL. Entire zone will typically maintain standing water with some drawdown over prolonged dry spells. Includes planting on perimeter safety bench as well as shallow bands within the main wetland and any embankments/bunds within the wetland. Highly visible from perimeter and offers high amenity with opportunities for further biodiversity enhancement (refer to Section 3.3.1.1).	· Eleocharis acuta. · Isolepsis prolifera. · Machaerina articulata. · Machaerina rubiginosa. · Shoenoplectus validus.
Deep water plants – Aquatic macrophytes Planting zone from 250mm to 500mm below PWL. Entire zone will permanently maintain standing water even during prolonged dry spells. Includes edges of deep open water pools where plants will naturally migrate to suit conditions.	· Eleocharis spacelata. · Shoenoplectus tabernaemontani.
Deep pools – Submerged macrophytes Planting in deep pools greater than 500mm below PWL. These will be rooted in the substrates and grow up to the surface. Can support some additional water quality improvements, biodiversity and amenity but are not considered critical to function and can be planted as discreet clumps as desired.	· Potamogeton chessmanii.

Planting zone and description	Plants
Littoral edges – Terrestrial Planting on perimeter and bunds extending from PWL to top EDD. This zone is above the standing water level at all times except during and immediately following rainfall. Soils are generally damp with good access to water for plants. Very important zone to reduce weed growth and support a low maintenance wetland. Littoral plants will transition into riparian planting in accordance with landscape intent.	· Carex secta. · Carex virgata. · Carex maorica. · Cyperus ustulatus. · Carex geminata. · Carex lessoniana. · Juncus pallidus. · Phormium tenax.
Diversity planting These species can be included in the wetland planting palette to enhance both the local biodiversity and add some interest to the wetlands through different growth forms and characteristics. Can be included as targeted planting in visible locations around the perimeter at PWL. All species will migrate above and below the standing water level to suit conditions.	· Myriophyllum propinquum. · Persicaria decipiens. · Ranunculus amph. · Gratiola sexdenta. · Cotula coronopifolia.

4 BIORETENTION – TECHNICAL GUIDANCE

People enjoying the sun at the mouth of Kumutoto Stream at Te Whanganui-a-Tara (Wellington Harbour). Kumutoto Stream was diverted into a pipe network in the 19th century to accodommate intensifying development in the central business district. Kumototo Stream was the first of many natural streams to be lost to development in Wellington. Water sensitive design can play a role in reconnecting Wellingtonians to their natural environment by bringing water back into its streets and enhance the mana of this taonga.

4.1 Introduction

This section provides technical guidance for the design of bioretention systems for stormwater treatment purposes.

Bioretention devices require a relatively small footprint area for a high level of treatment achieved (approximately 2% of their contributing catchment impervious area). Bioretention devices are suitable for use on a range of catchment sizes from street-scale to larger areas (up to 10ha).

4.1.1 Scope exclusions

This guideline does not cover:

- bioretention swales, planter boxes or tree pits
- bioretention devices with catchments larger than 10ha.

4.1.2 Basis of design

The design methodology in this guideline is based on the design approaches contained in recent New Zealand guidelines (GD01/HCC ITS and CCC) as well as research from the Facility for Advancing Water Biofiltration (FAWB) and resultant Australian design guidelines.

Key sizing assumptions and methods have been verified through continuous simulation modelling using local Wellington climate data. This modelling ensures that the design methodology responds to the local conditions, to support resilient performance over an acceptable lifecycle.

4.2 Bioretention – description

Sometimes referred to as raingardens, bioretention devices are vegetated filtration systems designed to provide enhanced water treatment through combined physical and biological processes.

- Untreated stormwater is discharged to the surface and percolates through a prescribed filter media.
- Treated flows are infiltrated to the underlying soils or discharged to the downstream reticulated network/watercourse, or a combination of both.
- Bioretention devices primarily provide water quality improvement but can also provide a small amount of mitigation of increased flows.

Bioretention devices can be designed at variable scales ranging from small street scape style systems with direct connection to surface flows, through to large scale systems with inlet diversion structures and high flow bypass arrangements. In all instances, the fundamental issues are the same:

- engaging the full filter media surface during small to moderate events
- carefully controlling the drawdown through hydraulic conductivity of filter media
- using suitable vegetation to support the treatment function
- maintaining infiltration and organics
- ensuring that the treated flows can be appropriately discharged.

4.2.1 Benefits and functions

Well-designed bioretention systems provide the following benefits:

- cooling stormwater entering downstream receiving environments and creating a cooler immediate surrounding
- providing an aesthetically pleasing landscape feature
- supporting vegetation in the urban environment
- providing habitat for plants and wildlife
- supporting community education and awareness through an understanding of the urban water cycle.

Due to the need for underdrainage and prescribed filter media, bioretention devices can be more expensive than other treatment devices like wetlands on a per square metre basis. However, the smaller relative footprint; and suitability as distributed networks of small-scale systems within the road corridor; makes bioretention devices an important component of water sensitive design.

As part of the public stormwater system, bioretention devices are preferred over proprietary filtration units as they provide

- improved removal of dissolved contaminants (ie nutrients and dissolved metals)
- multi-value benefits such as improved street amenity; detention of small to moderate storm events and better opportunities for community education.

Figure 26 below shows a cross-section of a bioretention device.

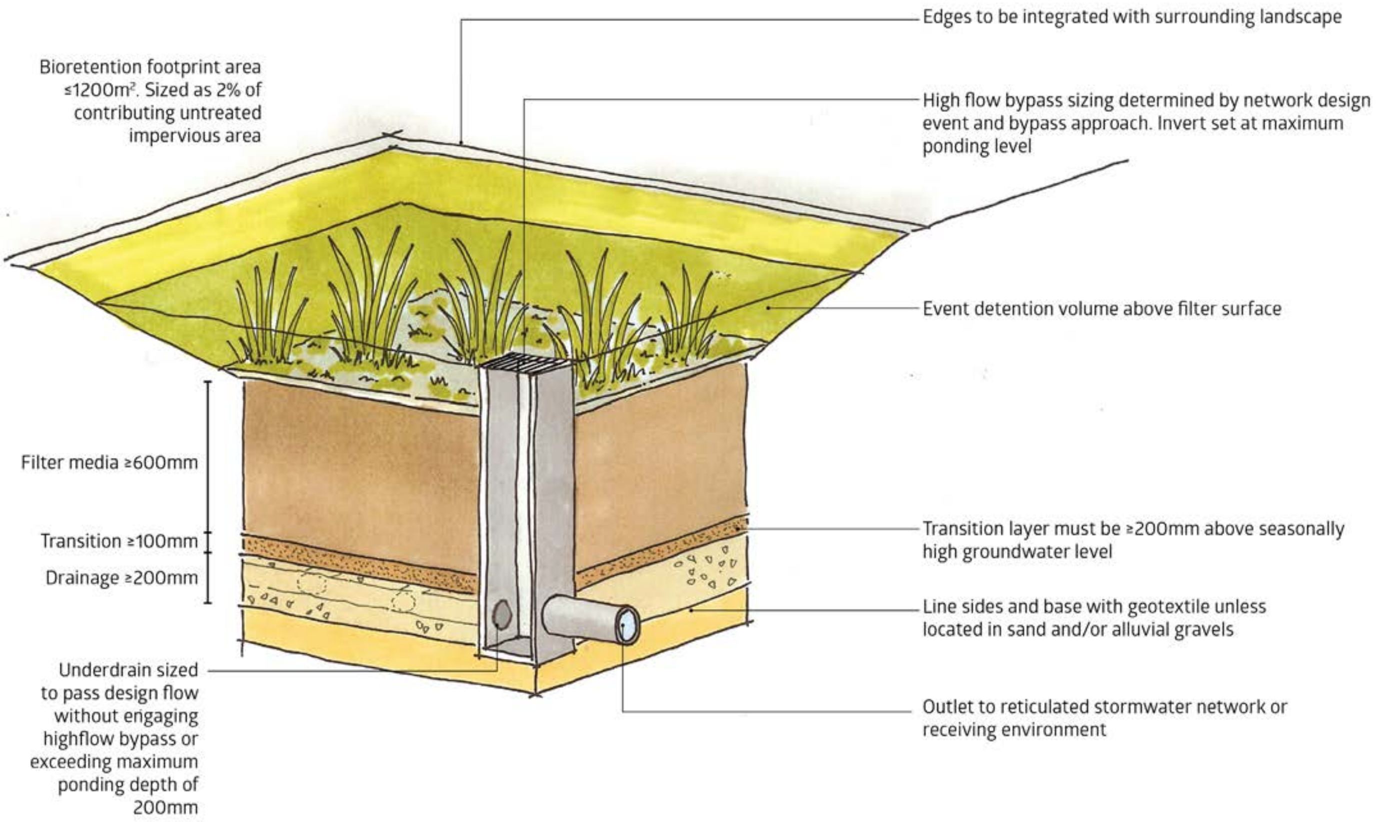


Figure 26: Bioretention cross-section.

4.2.2 Main components

The long-term function of bioretention devices depends on several components. These components support the complex treatment pathways of bioretention devices. Table 25 lists these components and provides a brief description.

Table 25: Bioretention main components.

Component	Description
Pre-treatment (optional)	Pre-treatment in the form of a gross pollutant trap, proprietary device, swale or forebay to remove coarse sediments, litter etc. This is particularly important for commercial/ industrial sites.
Inlets	Inflows to bioretention can be via surface (ie kerb cuts) or piped. Maintenance requirements must be considered with a preference for fewer, well designed inlets rather than multiple inlets, which can be prone to progressive blockage. Design must mitigate erosion effects.
Event detention ponding volume	Enables the engagement of the full filter media surface and provides temporary detention of inflows during moderate to large events. Ponding depth must be <200mm but may be extended with approval from Wellington Water's Land Development Team.
Filter media	An engineered media that allows for treatment, plant growth, water storage and biological activity. Saturated hydraulic conductivity and particle size distribution are critical to: · ensure than excessive fine particulates do not settle on the surface · allow the filtration of stormwater through the full graded depth.
Mulch layer	Reduces the maintenance requirements during establishment, provides an environment for biological activity and supports plant health during prolonged dry spells.
Plants	Remove nutrients and pollutants through combination of microbial activity on roots and uptake. Also maintain infiltration rates in filter media and carbon source to the system.
Transitional layer	A coarse sand layer that acts as a bridging layer to prevent migration of filter media to drainage.
Drainage layer	Underlying layer with high hydraulic conductivity to convey treated flows into the underdrains or to act as a reservoir to detain treated flows where the design includes infiltration (retention). Can be configured to extend below the level of the underdrain to provide increased retention storage.
Internal water storage (IWS) (optional)	The internal water storage (IWS) zone is a zone that sits below the invert of the outflow pipe and is included to promote retention and provide a water source for plants during dry periods. The IWS must be situated below the lower level of the transition layer to avoid backwatering into the filter media.
Overflow/bypass	Hydraulics must be configured to: · prevent excessive flows into bioretention · allow flows to bypass in large events and/or overflow from the ponded area in a controlled way.
Underdrain	Collection pipes to convey treated flows to reticulated network or receiving environment. Must be sized to ensure able to pass design flows without bypass or exceeding maximum ponding depth of 200mm. Underdrainage is required in all systems and can only be removed with approval from Wellington Water when in-situ infiltration rates are suitable.
In-situ infiltration	Infiltration rates of subsoil must be understood to ensure retention occurs. Retention function is impaired in poor soils. Where the design specifically includes retention through infiltration, the saturated hydraulic conductivity of subsoils must be evaluated.

4.2.3 Catchment land use

Bioretention devices are well suited to treat typical urban stormwater from paved surfaces such as roads, roofs and carparks and unpaved surfaces such as established grass and gardens. As with all stormwater treatment devices, bioretention devices are susceptible to excessive loading of fine sediments such as runoff from construction sites or disturbed ground. This is particularly important during the construction phase of land developments where:

- sediment loads from individual building lots can have a significant and irreversible impact on bioretention devices that have been constructed at the completion of bulk civil works
- discharge of high sediment loads can permanently degrade these devices even when fully established.

Bioretention devices must be protected from any construction related high sediment loads by keeping them offline until their catchment is established. Effective erosion and sediment control is critical for all land development projects at any scale.

Some land uses require additional pre-treatment of stormwater before discharge to the public network, to ensure that increased contaminant loads do not impact on public stormwater treatment devices. This includes paved areas from industrial/commercial developments (not including roofs), service stations and major arterial/State Highway roads. Pre-treatment must be provided within the private realm for these land uses (or within the road designation for NZTA controlled roads). This pre-treatment can include proprietary devices or other appropriate stormwater treatment with a documented maintenance regime in place.

Table 26 summarises different land uses and their suitability to be managed via bioretention devices.

Table 26: Summary of land uses applicable to treatment with bioretention.

Land use category	Suitability
Roofs (all land use categories)	Suitable.
Residential areas including all paved areas	Suitable.
Commercial (including warehousing, logistics and retail)	Suitable .
Industrial (including manufacturing and storage)	Suitable with pre-treatment.
Local roads (<10,000 VPD)	Suitable.
Arterial roads and highways (>10,000 VPD)	Suitable with pre-treatment.
Bulk earthworks and land clearance	Not suitable.
Construction sites (including in established catchments)	Not suitable.

4.3 Bioretention – Design

This section provides guidance on the key design factors that must be considered during design of bioretention devices.

4.3.1 Design considerations

The design of bioretention systems must carefully consider the site-specific context and respond to constraints such as soils, groundwater, topography, service conflicts, public safety, maintenance access and preferred urban design.

A site assessment must be completed at the outset of the project to ensure that solutions proposed for sites are realistic and optimal. This is especially important where developments propose a treatment train approach, where the sizing of downstream devices depends on the size of upstream devices. In these circumstances, changes in the size or function of devices at any position of the treatment train will potentially require redesign of other upstream/downstream devices, which is likely to be problematic. Therefore, designers should demonstrate a reasonably high level of confidence in the proposed design at all stages of development planning.

Due to the need for specific functional layers within a bioretention (ie ponding, filter media, transition layer and underdrainage), the vertical differential between the inlet and outlet is often the defining constraint during design. Bioretention devices covered by this guideline require a minimum of 900mm between the inlet invert (either crest of kerb cut/weir or pipe invert) and permanent outlet invert (including any allowance for seasonal groundwater levels or tides). This can be challenging on sites with limited grade and where connections into the existing network are fixed.

In situations where bioretention devices will be designed with infiltration to the in-situ soils (to support retention of stormwater flows), careful consideration must be given to the geotechnical suitability and risk of geotechnical instability. This must:

- consider the geotechnical structure of any slopes on the downward side and the implication of slope failure
- factor in whether the site includes unmodified site soils or engineered fill as part of development bulk earthworks.

Ideally, any large-scale systems that include infiltration should be located on undisturbed ground, which will naturally support infiltration. This is typically achieved in low lying areas, land in proximity to existing streams and/or ephemeral flow paths. This can provide connectivity with shallow baseflow and more free-draining deeper alluvial/colluvial soils. Locations with undisturbed ground should be identified through the initial site assessment and protected from unnecessary earthworks where appropriate. Where infiltration is part of the design, the assessment must include field testing of soils using a double ring infiltrometer by a suitably qualified person.

Bioretention devices are not suited to areas with high groundwater as they may become waterlogged for long periods. This could result in drowning of the plants and leaching nutrients into receiving waterways. Without specific design, the base of the bioretention (ie the bottom of the transition layer) should be at least 200mm above the seasonally high groundwater level, including consideration of potential increase in groundwater level with sea level rise where known.

Similarly, the design of bioretention devices must respond to the potential tidal impacts on outlet hydraulics and be designed in accordance with the tide levels (including sea level rise) provided in the Regional Standard for Water Services. Bioretention systems must not be constructed in situations where they receive constant baseflow from any connected stream or groundwater seep flows. This will result in rapid clogging of the filter media and failure.

4.3.1.1 Key design considerations

Table 27 provides a summary of some of the key design considerations that designers must reflect during design development, to integrate bioretention into the site while ensuring the device functions as intended over the entire lifecycle.

Table 27: Key bioretention design considerations.

Item	Consideration
Inflows	Ensure that the bioretention catchment drains to the bioretention area efficiently without causing nuisance surface ponding and that inlets are positioned to support safe inspection and maintenance. Where inflows are from a piped network, ensure that levels support pipe cover and grade and that any high drops do not pose a risk to public safety.
Machinery access	Consider how machinery will gain access to bioretention for construction and maintenance. Large systems over 100m^2 will require vehicle access to at least 50% of the perimeter (ie one full side) including to any dedicated sediment deposition areas at the inlet.
Pre-treatment	Where the catchment includes industrial/commercial land use, pre-treatment must be included prior to the bioretention.
Offline	Bioretention systems must be offline to peak flows. This can be achieved through surface inlets (kerb cuts) being set at the same level as the top of ponding depth, or a diversion structure that controls inflows from a piped network. Any circumstance where flows may be routed through the bioretention system during peak flows must be raised with Wellington Water’s Land Development Team.
Groundwater	If the seasonally high groundwater table is within 200mm of the proposed base of bioretention transition layer, the bioretention device will not function without specific design.
Underground services	Contact utilities (power, telecommunications water and gas) and check for locations of underground services in your area. If underground services are near or in the proposed bioretention location, try and relocate the bioretention area away from these services. If relocating is not an option due to site constraints, bioretention can still be used, however the services will need to be protected and marked on bioretention drawings. Note that service providers may have to dig up the bioretention to access services.
Overhead setback	Consideration should be given to overhead setbacks to ensure that construction and maintenance are not impacted or that any perimeter trees do not interfere with utilities such as power lines. Compliance with all relevant overhead utilities must take precedence in all circumstances.
Contaminated land	Contaminated land may pose a risk to the environment if exfiltration of surface runoff occurs. Other contaminated land areas may have contaminated groundwater that should not be allowed into the stormwater network. If either of these conditions are present at a site, the bioretention must be fully lined with an impermeable liner.
Flood protections	Bioretention must be placed away from any overland flow paths to avoid scouring of the device, and outside areas where ponding occurs more frequently than in the 10% AEP event.

4.3.1.2 Geotechnical guidelines for bioretention devices

The geotechnical guidelines in Table 28 must be applied in the design of bioretention devices.

Table 28: Geotechnical guidelines for the design of bioretention devices.

A: Can the bioretention device alter the natural groundwater levels?	**Yes**	Check Regional Standard for Water Services and Natural Resource Plan for groundwater diversion and abstraction rules.
	No	See other questions.
B: Is the bioretention device located above retained land?	**Yes**	Setback of 3x the apparent height of the retaining wall to the nearest part of the device. This setback may be able to be reduced with the advice of a geotechnical professional including where the bioretention is itself formed by a retaining structure.
	No	See other questions.
C: Is the bioretention device located below retained land?	**Yes**	Setback of 3x the apparent height of the retaining wall to the nearest part of the device. This setback may be able to be reduced with the advice of a geotechnical professional.
	No	See other questions.
D: Is the bioretention device on or near a slope >5^0?	**Yes**	Risks of slope failure must be considered at the earliest stage of design. Geotechnical investigations are needed across the entire design area to understand the underlying soils, and designs must accommodate all geotechnical constraints (such as soil instability). The bioretention device must be fully lined. A bioretention device may only be used on slopes steeper than 14° (25% or 1V:4H) if the effects have been assessed by a geotechnical professional. If device is at the toe of a slope, the sides of the device should be structurally sound as to replace any loss of support to the surrounding ground that would have been provided and must be fully lined. If device is at the crest of a slope the sides of the device must be fully lined and setback 2x the depth of the excavation from the crest.
	No	See other questions.
E: Is the bioretention device adjacent to or nearby any structures or foundations (including horizontal infrastructure)?	**Yes**	If the device is closer than 2x its depth to a structure or foundation etc. seek professional geotechnical advice. Where bioretention devices are required to be close to structures, or to trafficked roads, structural support may be required. This can be avoided by locating devices away from loads producing significant lateral forces. Otherwise seek professional geotechnical advice.
	No	See other questions.
F: Is the bioretention device near a public or private road?	**Yes**	The device should be designed to prevent the influx of water into the road subgrade (unless the road design allows for this). The sides of the device should be structurally sound as to replace any loss of support to the surrounding ground that has now been removed.
	No	See other questions.

4.3.1.3 Safety in design

Bioretention systems are low risk as they only detain a shallow depth of water for a short period of time (drawdown in approximately two hours following rain). However, there are important considerations for safety that must be considered during the design. These safety considerations include ensuring that:

- there are no excessive drops from pedestrian areas to filter media. Where vertical drops exceed 200mm, the design must include edge battering or surface kick boards, to reduce the risk of trips and/or falls
- there are no unmarked drops from trafficable vehicle areas. This includes public roads and low speed environments like carparks. Where drops cannot be avoided with vegetated batters, wheel stops or kerbs are required
- maintenance of inlets can be completed in a safe way, with a preference for minimising conflict with live traffic lanes without the need for extensive traffic management
- kerb cuts do not present undue risk to traffic or cyclists. This requires consideration of the location and design of inlets and visibility
- fully grown vegetation will not obscure sight lines in areas where this may be an issue for traffic and pedestrians
- vegetation will not overhang paths and present any trip hazards. This will impact on the selection of plants to be used around the perimeter.

These safety considerations can be managed through the use of street furniture and other landscape elements.

4.3.1.4 Site selection

Well-designed bioretention systems provide a resilient treatment device that can be easily integrated into the surrounding landscape. Due to the ability to design at a range of scales, bioretention devices are well suited for integration into more naturalistic settings like parks, or in heavily constrained and engineered contexts such as road verges and hard landscapes.

Edge details and the interface with the nearby finished surfaces must consider the broader landscape context and in high profile locations, must be supported by qualified landscape architects as part of the design team.

Bioretention areas should be integrated into the finished landscape to add amenity and to increase community support and engagement.

The surface of the bioretention needs to be level, so this needs to be considered from the outset of earthworks planning and modelling, especially on naturally sloping sites. While terraced Bioretention devices can be a solution in some locations (particularly where there are multiple inlets) they should generally be avoided as they do not support the uniform engagement of the systems. Designs where it is proposed to use terraced or stepped systems must be discussed with Wellington Water's Land Development Team at the outset.

Due to the importance of elements such as filter media and drainage, bioretention devices must not be oversized to align with landscape design intentions. The oversizing of devices is likely to impact on plant health (through excessive drying) and increased capital expenditure/operational expenditure costs, with only marginally improved overall treatment.

Similar character and aesthetics can be seamlessly integrated using appropriate plant selection in standard garden beds. These garden beds can then be positioned next to specific bioretention devices that conform with all technical design requirements.

While it will generally be more cost effective to construct bioretention systems directly into natural or engineered ground, these systems can also be supported by using retaining structures to create level terrain and support the required functional layers. This can be effective in:

- developments on steep topography where retaining walls are used to create roads and building lots.
- high profile public realm where the raised bioretention devices can be integrated with seating and other designed features.

In any instance where retaining structures are required (including earth bunds), the design must ensure that the system will support ponding and controlled drawdown through the filter media, without causing instability or ongoing leakage that could result in piping and structural failures.

Vehicle damage to bioretention devices is a common problem resulting in damaged plants, damage to hard/soft edges and potential public safety risks. To prevent vehicles driving on bioretention areas, it is necessary to consider appropriate traffic control solutions as part of the design. Providing physical barriers such as kerb and channel (with breaks to allow surface flow inlets), bollards and/or street tree planting should be considered.

For bioretention placed near roadways or pedestrian paths, vegetation selection needs to consider both the risk of damage through unintended walking paths and the need to maintain sight lines and passive surveillance from a safety perspective. An example of using vegetation to prevent accidental entry into the device is shown in Figure 27.

Figure 27: Example of Bioretention in pedestrian areas. Wynyard Quarter, Auckland.

4.3.2 Technical device sizing

The sizing methodology for bioretention is outlined in this section. The sizing will vary depending on treatment, detention and retention requirements of bioretention areas.

Bioretention devices are a versatile treatment system for small to medium catchments to manage flows directly from the surface or from reticulated pipe network. Bioretention devices are sized relative to the contributing catchment, which means that several small distributed systems or a larger more centralised system can be included in developments.

4.3.2.1 Key design requirements for bioretention sizing treatment footprint

The sizing of bioretention devices for water quality purposes is to be based on the footprint of the filter media, relative to the contributing impervious catchment. This simplified method reflects the function of these systems in terms of surface detention, through flow and discharge over a range of operating conditions.

A maximum footprint area of 1,000 to 1,200m^2 is recommended for the bioretention systems covered by this guideline.

The maximum area is dictated by constructability to achieve even infiltration rates, even flow distribution and maintenance practicability.

Bioretention devices must be sized based on a relationship of the filter media area being 2% of the contributing untreated impervious area.

This relationship is based on the material and functional properties detailed in Section 4.3.3.2, a ponding depth of 200mm and the design of inlet/outlet hydraulics covered in Section 4.3.3.

This 2% area has been shown to enable bioretention to treat approximately 90% of the mean annual stormwater volume with the remainder bypassing.

This size will also retain adequate moisture in the inter event periods and support robust vegetation, which will maintain the infiltration rates over the long term.

Where bioretention devices are constructed with sloping batters below the filter media surface due to ground instability concerns, the filter media area must be calculated as the footprint of the bioretention measured at the midpoint of the filter media depth (ie 300mm below the finished filter media level). This is particularly important for smaller scale systems where the actual footprint of the device (including ponding depth) can be significantly greater than the defined filter area that is the basis for sizing.

4.3.2.2 Key design requirements for media layer depth

The depth of the media layer determines what types of plants can be grown in bioretention as well as affecting pollutant removal capacity.

The minimum bioretention depth is 600mm of media. This depth can only be changed with specific design and approval of Wellington Water.

4.3.2.3 Key design requirements for ponding depth

The depth of water that can be temporarily ponded on the filter media surface governs the volume of water able to be treated during rainfall events.

This detention storage is critical to enable flowrates in exceedance of the filter media infiltration rate into the system to be attenuated before treatment.

The depth is governed by a need to avoid over attenuation of inflows, resulting in physical settlement of fines, while aiming to treat approximately 90% of mean annual stormwater volume.

Instances where the ponding depth must be reduced will require modelling to demonstrate that the size has been increased accordingly to achieve the same overall treatment effectiveness.

4.3.2.4 Key design requirements for retention

Where retention of flows is required, internal water storage (IWS) can be provided in bioretention. IWS can be provided through the use of a zone at the base (below the underdrains) that does not drain out to the stormwater network, but infiltrates over a period once it has stopped raining. Depending on the site-specific exfiltration rate, IWS can also provide a water source for plants between rainfall events.

The main functions of the IWS are to increase retention and support plant growth over dry periods. There may also be some enhanced treatment due to the anoxic conditions that develop.

To meet specific retention requirements, the required retention volume is calculated. To account for losses to exfiltration during the design event use Equation 5 (below).

Equation 5: Calculation of the required internal water storage volume.

$$V_{IWSreq} = REV - i \times A_{bio}$$

Where:

V_{IWSreq} = required volume of the IWS zone (m^3)

REV = retention event volume (m^3)

A_{bio} = bioretention surface area (m^2)

i = exfiltration rate of base soils ($m\ day^{-1}$)

The final volume of the IWS is then determined by calculating the volume below the level of the underdrains, based on the footprint and depth and the corresponding void ratio in Equation 6 below. The depth is then iteratively adjusted until the required volume of the IWS is achieved.

Equation 6: Calculation of the final internal water storage volume.

$$V_{iws} = A_{UD} \times D_{IWS} \times e_{IWS}$$

Where:

V_{iws} = volume of IWS zone (m^3)

A_{UD} = average area of the underdrainage layer (m^2)

D_{IWS} = depth of the internal storage below underdrain outlet (m)

e_{IWS} = internal water storage void ratio (-)

4.3.2.5 Hydraulic design

Inflows to the bioretention can be controlled via either an open surface flow (such as a kerb cut) or through controlled diversion from reticulated stormwater pipes. The control of inflow rates is critical to enable the most contaminated initial flush of stormwater run-off into the system, while protecting it from potentially damaging high flowrates. This is done by allowing flowrates up to the Water Quality Flowrate (WQF) into the systems before bypass is engaged.

The calculation of the WQF is covered in Section 2.4.3. It is important to ensure that this WQF is calculated based on the flowrate for the contributing catchment to be treated (including pervious and impervious fractions). The design of bypass and overflow structures must be calculated for the entire catchment flows, regardless of whether there is additional upstream treatment as part of a treatment train. This will mean that the system will be resilient to the full range of potential flowrates and will treat only the portion on which it is sized for water quality management.

4.3.3 Design components

This section provides guidance on the design of the individual components of a bioretention device.

4.3.3.1 Inlet design

The design of inlets is critical to support long term treatment within a cost effective and practical maintenance regime. Inlets must be designed to enable the full water quality flowrate into the device. Outlets must enable the treated flows to discharge without causing any backwater effects that could reduce the overall treatment performance.

The specific design of inlets is generally governed by the scale of the catchment and the position of the bioretention relative to upstream infrastructure. Examples of possible inlets include:

- Kerb cuts to receive flows directly from roadside runoff, with water level in the event detention zone controlling feedback to enable bypass of peak flows.
- Open backed catch pits where flows are able to preferentially discharge to the bioretention with feedback controlling bypass. This is well suited where shallow lateral pipes are to be conveyed to the bioretention or where breaks in the kerb are not approved.
- Sheet flow via flush perimeter. This typically only applies to small systems with small catchments or long narrow systems with low sediment yields (ie pedestrian paths).
- Piped inflow into bioretention with diversion hydraulics to achieve bypass of peak flows.
- Pumped inflows where harvesting of stormwater from the larger drainage network is desired.

Inlet maintenance

Maintenance of inlets is a key consideration, as this is where a large number of bioretention devices fail. The inlet designs below should be avoided to reduce the risk of failures:

- Small aperture perforations through kerbs. These are particularly prone to blockage and will rapidly fail without constant upkeep.
- Multiple kerb inlets without adequate design for maintenance. The tendency to include multiple openings in close proximity to support distributed inflows (ie castellated kerbs) should be avoided. This is because the flows will generally only engage the upstream inlet and the duplication can increase maintenance burden, cost and risk of progressive blockages.
- Siphons or ‘bubble ups’ where standing water is retained between events. These are prone to blockage without increased maintenance and may only be used with approval from Wellington Water’s Land Development Team.
- Piped inflows without adequate scour protection.
- Flush perimeters (for sheet flow) without a set down to the filter media. These will be prone to blockage as vegetation and soil levels rise over time, resulting in worsening nuisance ponding on adjacent paved surfaces.
- Use of reno mattresses or gabions as aprons with risk of short circuiting.

Streetscape kerb cuts

For bioretention systems serving roads or carparks, inlets are typically formed from kerb cuts. The width of the opening is governed by the design flow rate entering the system. Kerb inlets aligned perpendicular to the flow path should be designed using the broad-crested weir approach. However, where the inlet is orientated parallel to the flow path (ie side cast to inlet from channel), the length of opening must be increased by a factor of 1.25 to minimise the potential for bypass of design flows. Equation 7 can be used to design the kerb opening for the required design flow to the bioretention device.

Equation 7: Determination of kerb opening dimensions for given design flow rate.

$$Q_{weir} = C_w L h^{3/2}$$

Where

Q_{weir} = design flow through kerb opening (m^3/s)

C_w = weir coefficient (1.66)

L = length of kerb opening (m)

h = depth of flow in kerb (m)

The shape of the inlet can also greatly affect the behaviour of both low and high flows. Desirable attributes of a kerb inlet are:

- Rounded or tapered kerb edges (with sufficiently large radius for the design flow rate).
- Concrete apron with a grade of approximately 10% to prevent localised ponding and sediment build-up on the road.
- Energy dissipation at the toe of the apron using grouted rock (spacing of rock should not create channelled flow) or a concrete apron installed at the level of the filter surface.

Flow diversion using raised structures within the kerb and channel should not be used as this poses a potential hazard to bicycles and motor vehicles.

Where flush kerbs are to be used (ie support full sheet flow), a set-down from the pavement surface to the vegetation must be adopted. This allows a location for sediments to accumulate that is off the pavement surface. Generally, a set down from kerb of 50-100mm to the top of the filter surface is adequate. This set-down can be part of the overall event detention storage depth.

Figure 28 shows two approaches to inflow and outflow design using street kerb cuts.

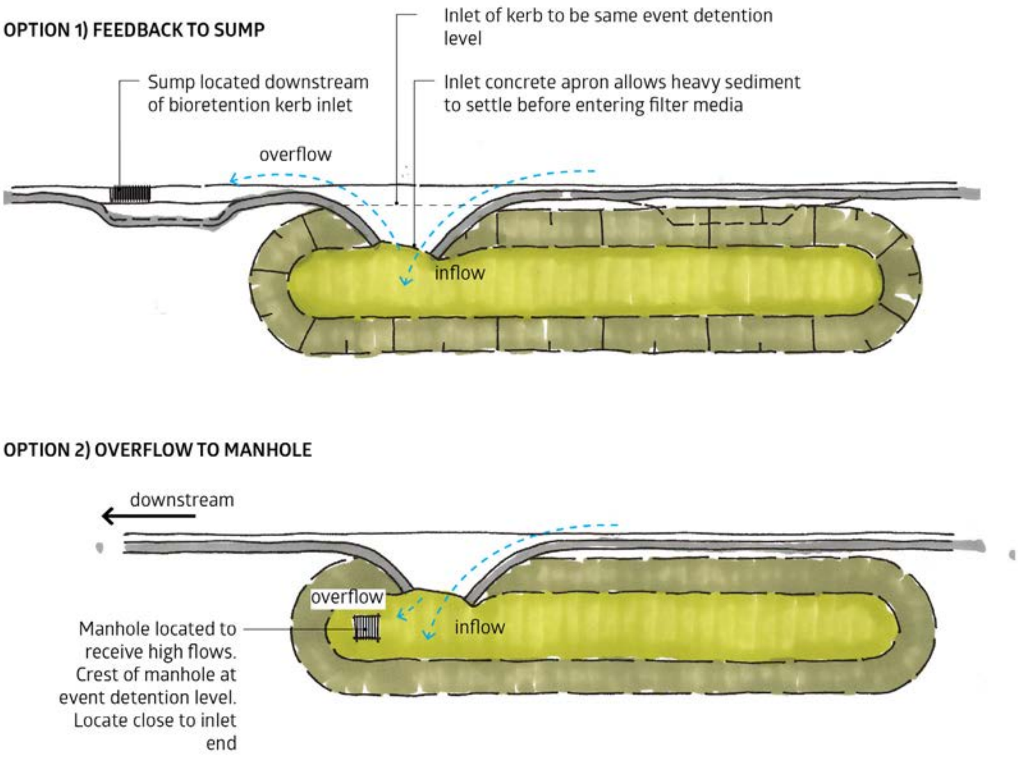


Figure 28: Bioretention inflow and outflow locations.

Piped inlets

On larger bioretention systems, inflows will typically be via piped flows from the reticulated stormwater network. These inflows will discharge concentrated flows to the surface of the bioretention, with protection required to ensure that energy is dissipated to reduce the risk of scour. As with smaller systems, the entire filter media needs to be engaged during rainfall events, with inflows ponding in the event detention depth. Once the filter media is engaged, the risk of scour is reduced and flows are distributed across the full treatment area.

While it can be beneficial to have multiple inlets around the perimeter of larger bioretention systems, this is not a strict requirement and needs to be balanced against the increased maintenance requirements.

The critical requirements for the design of piped inlets into bioretention systems are summarised below:

- All incoming stormwater pipes must comply with the Regional Standard and Regional Specification for Water Services for design, materials and construction.
- Inlet pipes must include headwalls founded on suitable footing and fitted to the pipe outlet to prevent any slumping, rotation or moving. Note that this will require headwalls to be located on in-situ ground (or compacted fill) rather than directly onto imported bioretention media. Where a proprietary headwall is not used (such as natural rock, timber or other design for aesthetics) the designer must demonstrate that the headwall will be stable over the expected design life and operating conditions.
- The invert of the pipe outlet must be no more than 100 mm above the surface of the filter media. Where a drop is unavoidable, a rock armoured chute must be included with a maximum grade of 1V: 5H. Any rockwork must be designed to withstand the design flows.
- A rock apron is required for piped inflows from contributing impervious catchments <2ha. This must comprise 200–300mm thick hand placed angular rock placed onto either in-situ ground or well compacted filter media to form a tight interlocking matrix. A layer of geotextile must be placed beneath the apron and crushed rock (GAP 20 or similar) swept into voids to reduce pores. The surface of the apron must be as level as possible to enable periodic removal of accumulated sediments. Reno mattresses or gabions must not be used as inlet protection, due to the risk of short-circuiting.

- A cast in-situ concrete coarse sediment forebay with energy dissipation is required for contributing impervious catchments > 2ha where high flow bypass has not been included. This forebay must be constructed on in-situ ground and must not be formed directly onto the imported filter media. The design of the forebay must be in accordance with Figure 29 below. The size of the forebay needs to respond to the expected catchment sediment loads and cleanout frequency, but as a general rule must:
  - have a length 5x the inlet pipe diameter (with a minimum of 3m)
  - have a width at interface with bioretention 5 times the inlet pipe diameter (with a minimum of 3m)
  - be 200mm thick 25 MPa concrete with 665 mesh or similar
  - include access for maintenance
  - include set down >100mm
- Planting next to the inlet must be robust grasses and sedges (ie no shrubs) and be planted at a density of 6 plants/m^2.
- On larger systems treating greater than 2ha, the planting plan must reflect the variable moisture levels where plants:
  - closest to the inlet are more tolerant of wetter conditions
  - at the downstream ends and perimeters are more tolerant of dry conditions and prolonged period with moisture stress.
- Design of the inlet pipe and headwall must consider public safety with inclusion of fencing/signage for drops greater than 1m.

Figure 29 shows the coarse sediment forebay design requirements.

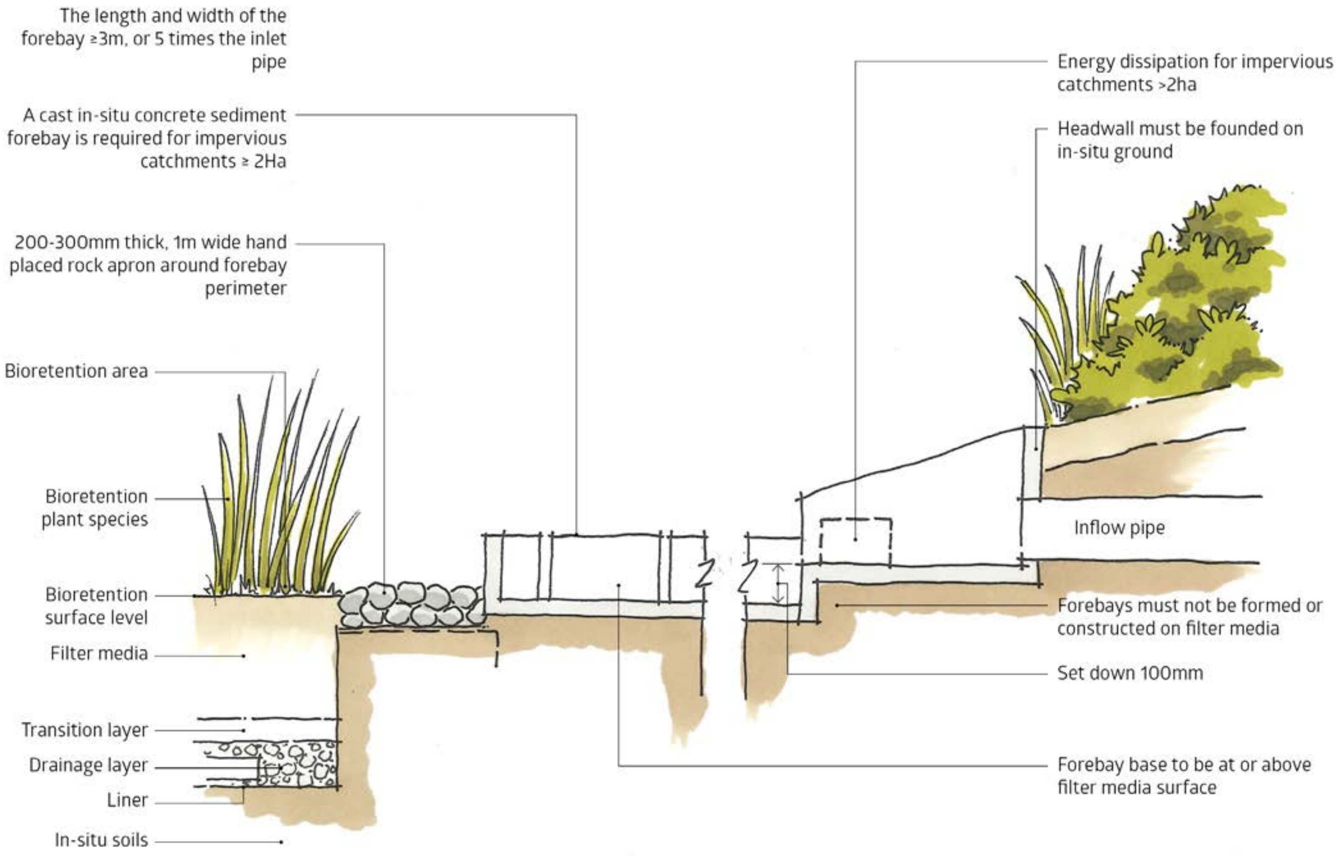


Figure 29: Coarse sediment forebay requirements.

4.3.3.2 Filter media

The media used for bioretention devices has a fundamental role in water quality treatment, water attenuation and supporting associated vegetation and their treatment pathways.

The filter media is intended to act as a graded filter. This enables sediments and fine particles to pass into the media and be filtered through the full depth, rather than only the surface, which may result in progressive clogging and loss of function. This is achieved by the specified required particle size distribution and the use of a free draining sandy loam. The hydraulic conductivity of the media is intended to pass the flow at a rate that reduces the amount of physical settling onto the surface (which can increase clogging) while still slowing the water down to enable increased contact time with the biological processes within the root zone.

The soil must also be able to support the specified vegetation including during prolonged dry spells and be free of contamination. These functional requirements for the filter media must be balanced in the selection of a suitable product to use.

Table 29 provides the key soil properties that must be achieved for the filter media. These properties must be verified through soil testing by an approved laboratory with at least one sample taken for every 50m^3 supplied.

Table 29: Bioretention media specifications (FAWB 2009).

Item	Requirement
Filter media depth	Minimum 600mm, unless specially designed and approved by Wellington Water's Land Development Team.
Saturated hydraulic conductivity	Between 100mm hr^{-1} and 250mm hr^{-1}
Plant available water	10% by volume
Organic matter	5% by weight
pH range	5.5–7.5
Electrical conductivity	< 2.5 dS m^{-1}
Total nitrogen	< 1,000mg kg^{-1}
Orthophosphate (PO43-)	< 80mg kg-^{1}
Total phosphorus	Leachate testing required if >100mg kg^{-1}
Total copper	≤ 80mg kg^{-1}
Total zinc	≤ 200mg kg^{-1}

The hydraulic conductivity of the filter media must be:

- measured using the *ASTM F1815-06 test method* or an approved alternative
- 100–250mm/hr.

The *ASTM F1815-06 test method* uses a compaction method that best represents field conditions and is available in most labs that certify sandy loams for sports applications (golf courses). All testing must be done in advance of procurement and delivery.

While the particle size distribution (PSD) is not an accurate predictor of the final infiltration rate, it is a useful consideration to ensure the graded filtration of sediments and to maintain soil structure. A PSD must be provided in addition to the testing of hydraulic conductivity for consideration by Wellington Water (and the designers). The filter media should meet the following particle size distribution:

- 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).

It is essential that the total clay and silt mix is restricted to reduce the likelihood of structural collapse. A clay and silt content of up to 5% can be accepted at the discretion of the designer, as long as the saturated hydraulic conductivity requirement is achieved and the media is well graded overall. There should be no gap in the particle size grading and the composition should not be dominated by a small or large particle size range.

4.3.3.3 Transition layer

The transition layer acts as a barrier between the filter media and the underdrainage to ensure that material is not passed through to the drainage layer. As such, it is specified based on its particle size range relative to both the filter media above and drainage aggregate below. Under no circumstances should geotextiles or filter cloths be used instead of the transition sands, as these are susceptible to progressive blockage, which will gradually clog the entire system and cause it to become water-logged.

The transition layer is to be 100mm deep and include washed well graded coarse sand with minimal fines, with a minimum saturated hydraulic conductivity of 1000mm/hr. A particle size distribution for the sand must be provided to ensure that it meets the required grading and the bridging criteria outlined below. The bridging criteria are based on the largest 15% of the filter media particles bridging with the smallest 15% of the sand particles. These criteria result in smaller voids, which prevent the migration of filter media particles into the sand. Equation 7 shows the required bridging criteria in the design of the transition layer.

Equation 8: Transition layer bridging criteria.

Bridging criteria = D15 (transition sand) ≤5 x D85 (filter media)

= D15 (drainage layer) ≤5 x D85 (transition sand)

No heavy machinery must operate within the bioretention system once the underdrains have been placed. All transition sands (and subsequent layers) must be distributed and spread from the perimeter with an appropriate excavator or conveyor system. The surface of the transition layer must be flat and free from localised depressions. A spreader bar or equivalent should be used.

4.3.3.4 Drainage layer

The drainage layer provides a free draining layer underneath the transition layer, to collect treated runoff and enable it to pass freely into the collector drains for discharge. Where the system is designed specifically for retention (ie optimised infiltration), the drainage layer must extend below the outlet invert and provide attenuation storage within its voids. The drainage layer is to be a fine, washed gravel (7mm pea metal) to be compatible with the overlying coarse sands to prevent unintended migration.

The drainage layer is to be a minimum of 200mm deep must be washed aggregate that is suitable for wetting and drying without any loss in structure.

Where modular storage cells are proposed to increase the attenuation voids, these must be entirely beneath the invert of the outlet drain. These cells must also include a further transitional aggregate size to ensure that gravels will not pass into the cells.

Where alternative materials such as recycled glass or salvaged aggregates are available and deemed suitable for use, these must be discussed with Wellington Water and used to reduce the overall carbon footprint of projects.

4.3.3.5 Underdrains

Underdrains are required to collect treated flow and convey it to either the downstream reticulated stormwater network or directly discharge to a stream or coastal waterbody. Underdrainage must comply with the following standards:

- All underdrains must be uPVC unless agreed with Wellington Water. PE pipe may be used in instances where uPVC is not supported.
- Underdrains must be smooth walled (internally).
- Underdrains must be pre-slotted with 1–2mm slots.
- All pipework outside of the drainage layer (including within transition layer) must be solid walled.
- All joins and fittings must be fixed with approved solvent cement and fully bonded prior to any backfilling.
- A filter sock must not be used in any circumstances.

4.3.3.6 Permeable geotextile liner

The sides and base of bioretention devices must be lined with a permeable geotextile liner, unless these devices are located in sand and/or alluvial gravels. The liner will prevent the migration of in-situ soil particles into the bioretention media and drainage layer.

This is particularly important in soils with high clay content that can easily migrate and progressively bind up the filter media. Similarly, the bases of bioretention devices are susceptible to long term settlement in clay soils, with a risk of the underdrainage gradually receding into the in-situ soil, resulting in blockage.

The use of permeable geotextile liners must be weighed against the potential of reducing the exfiltration capacity of the bioretention, in instances where retention is required. Wherever a liner is required, the highest flow rate filtration class should be specified to reduce the impact of flow retardation on exfiltration rate.

The permeable geotextile liner should be:

- lightweight, non-woven, needle punched geotextile
- strength class B or stronger to reduce the risk of damage during installation
- filtration class 3 to ensure flow retardation is minimised.

Permeable geotextile liners must not be used between bioretention layers.

4.3.3.7 Impermeable liner

In some instances, an impermeable liner may be required on the base and/or sides of the bioretention device. Situations where this may be required could include:

- Contaminated in-situ soils where increased exfiltration could mobilise contaminants into groundwater.
- Situations to avoid any discharge of water where soil stability issues and/or unstable slopes are identified with geotechnical advice.
- Adjacent to roads where transport engineers have specifically identified a need to reduce discharge of moisture into the sub-base.
- Where treated stormwater is to be harvested for reuse with desire to optimise volume captured to increase reliability of scheme.
- Where underlying soils have excessive infiltration rates and exfiltration could impact on a sensitive downstream watercourse.

Where an impermeable liner is required, it can include either a Geosynthetic Clay Liner (GCL) or 1.5mm HDPE with a verified permeability of less than 1 x 10-09m/hr. Any proposed alternatives must be approved by Wellington Water.

Installation of the impermeable liner must comply with manufacturers specifications. Where a liner extends above the level of the filter media, consideration must be given to maintenance of soil on the perimeter batters to avoid slumping.

In instances where only the sides require lining (such as small systems adjacent to roads), it may be feasible to line the bioretention with pre-cast or cast in-situ concrete units. These units should only be used where required (such as need for retaining of edge), to reduce the carbon footprint of the production of concrete.

4.3.3.8 Outlet design

The outlet from bioretention systems is critical to ensure that the treated flows can discharge to the downstream environment in a controlled way, without risks of backwatering or damage to the bioretention. This includes the management of overflows when the ponding depth is at capacity, and the discharge of treated flows from the base of the system.

4.3.3.9 Overflow design

Bioretention devices must be designed with provision for overflow. This is to manage inflows once the ponding depth is full. Provision for overflow can be achieved through any of the following three design aspects:

- **Raised open manhole**: The inclusion of a raised open manhole within the filter area.
- **Feedback to kerb**: Feedback to a kerbside catch pit.
- **Overflow spillway**: A constructed spillway in large systems.

These design aspects are discussed separately below.

Key design requirements for raised open manholes

A raised manhole is included in all bioretention devices except small streetscape systems with direct feedback connection to a kerbside catch pit downstream of the system.

Design requirements:

- Located within the filter footprint.
- Generally best to be close to the inlet, but with flexibility to position to align with preferred underdrainage layout.
- Crest of manhole set at the top of the event detention ponding depth.
- Manhole sized based on Regional Standard for Water Services, to pass maximum expected flow into system (unless secondary spillway included) with acceptable head and freeboard.
- Manhole founded on solid compacted footing and installed level.
- All pipe penetrations well secured with waterproof sealant.
- Manhole covered with removable scruffy dome cover for manholes greater than 900mm diameter. Smaller systems may have alternative smaller manhole risers with compatible grates.
- Outlet pipes from underdrainage connected into manhole and visible via surface grate for periodic inspection.
- Located close to pedestrian access.
- Planting around immediate surrounds with low vegetation to reduce risk of blockage.

Figure 30 shows bioretention outlet component and design flows.

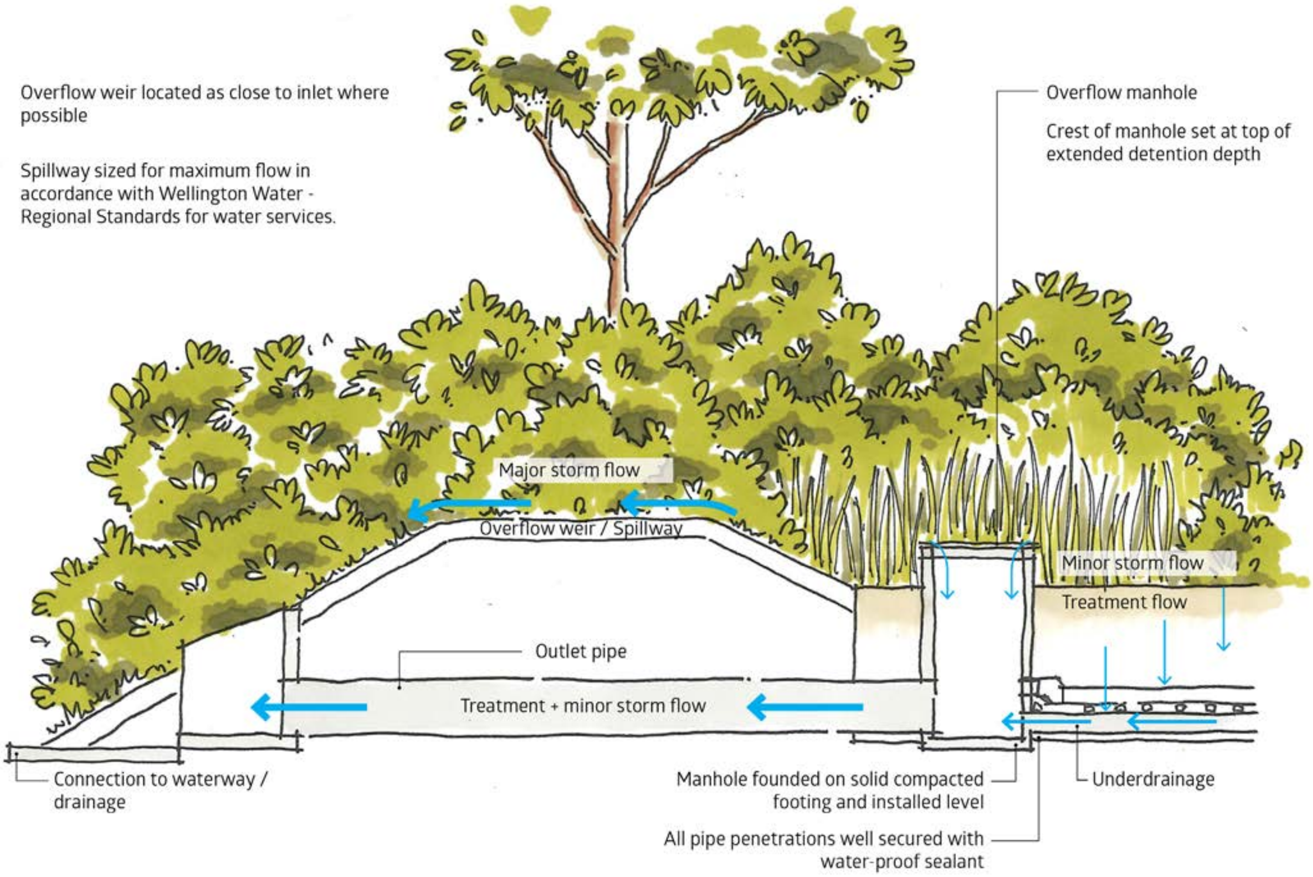


Figure 30: Bioretention outlet component and design flows.

Key design requirements for feedback to kerb

Feedback to kerb is used in small streetscape systems with direct surface inflows from kerb and channel; and levels which support feedback.

Design requirements:

- Standard kerbside catch pit located immediately downstream of kerb inlet to bioretention.
- Invert of kerb channel at bioretention set at the top of design event detention ponding depth.
- Design and spacing of catch pits to comply with Regional Standard for Water Services as a minimum.

Key design requirements for overflow spillway

Overflow spillway is included in large scale systems:

- that may be subject to larger prolonged flows during infrequent storm events
- where the discharge is compatible with downstream overland flow paths and will not cause flooding or erosion issues.

Design requirements:

Where possible, spillway must be close to inlet.

- Spillway sized for maximum possible flow into device in accordance with Wellington Water – Regional Standards for Water Services.
- Spillway sized based on broad crested weir equation.
- All perimeter levels (batters) must allow for full engagement over spillway and freeboard.
- Spillway crest must be defined with concrete beam and wing walls founded on a sound well compacted footing.
- Spillway design to include rock protection on both upstream and downstream face.

4.3.3.10 Underdrain design

The inclusion of underdrains in all bioretention devices is important to ensure that the systems will function for the intended lifespan.

- This includes systems that primarily rely on infiltration of treated flows.
- In this case, the inclusion of underdrainage provides a safeguard against progressive clogging of underlying soils.
- Clogging can result in backwatering and prolonged saturation of the filter media, which is likely to lead to failure.

Any circumstances where outlet connections are not achievable and the primary network is proposed to be entirely managed through infiltration must be raised with Wellington Water.

The underdrains must be:

- positioned entirely within the drainage layer
- designed to ensure that the intended design flow can pass through the system without causing any backwatering into the filter media which can impact on treatment performance.

Inspection risers must be included on all systems to enable CCTV inspection of underdrains and facilitate cleanout (rod or jet) as required.

All underdrains must be slotted rigid PVC without any filter socks. All collector pipes and pipes that extend outside of the drainage layer must be solid walled to avoid any short circuiting.

Small scale streetscape systems will typically have a single underdrainage line connecting into the outlet manhole with a riser at the upstream end. For larger systems, the design of the underdrains must include calculation of the hydraulic performance of the entire network. Figure 31 below provides an indicative schematic of a possible underdrain layout for a large scale bioretention system.

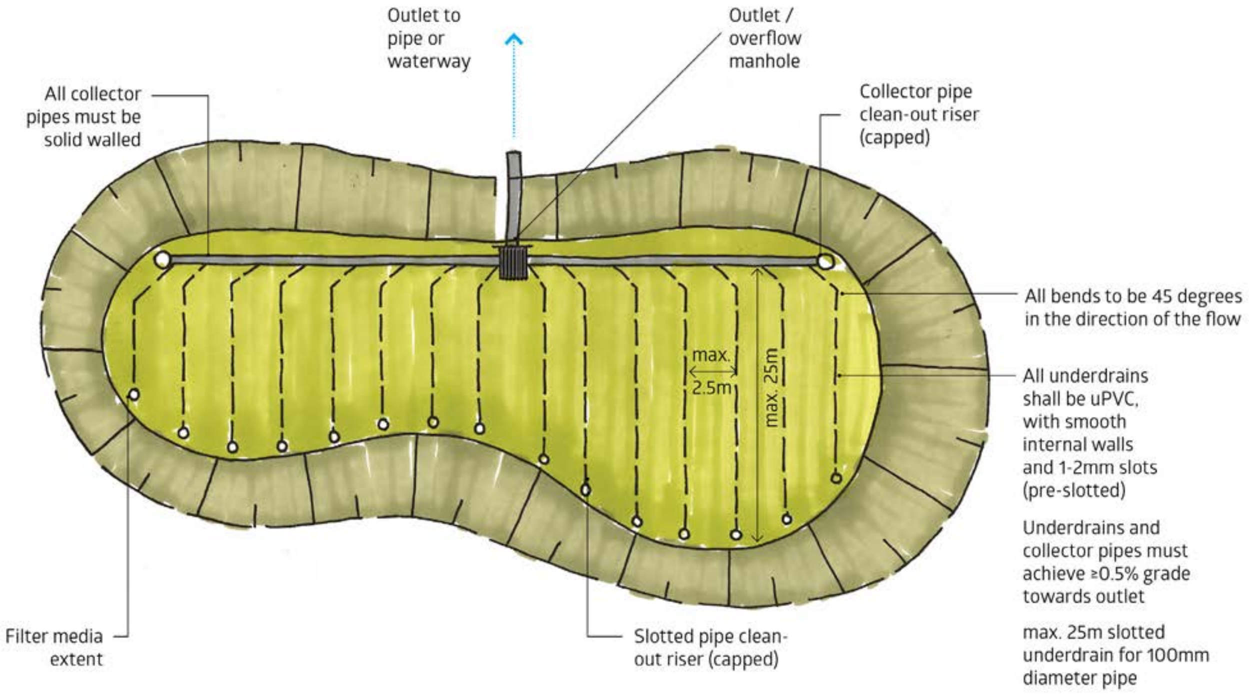


Figure 31: Underdrainage components.

Sizing of the underdrains for large systems (>3m wide and/or >25m long) should follow these steps:

1. Confirm outlet levels for underdrain and ensure these are compatible with downstream conditions and proposed levels to the surface (including filter media and ponding).
2. Develop a provisional underdrain layout based on the proposed bioretention dimensions.

3. Confirm that underdrains/collector can achieve a constant grade of 0.5% towards outlet.
4. Calculate the maximum infiltration rate of the filter media based on the verified testing of the proposed sandy loam filter media and only the surface footprint of the bioretention defined by the area of underdrains connected by a single collector pipe.
5. Check the flow capacity for the proposed slotted pipe layout, see Table 30.
6. Check the flow capacity on the solid collector pipes, see Equation 9 below.

Where capacity issues are identified, revise the layout, increase the pipe size or do both of these things.

Equation 9: Calculation of the number of underdrains required for large bioretention devices.

$$Q_{slotted} \times N_{\#\,pipes} > 1.2 \times q_{\max}$$

Where:

$Q_{slotted}$ = maximum conveyance of a single slotted pipe as per Table 30

$N_{\#\,pipes}$ = number of parallel slotted pipes in zone (max 25m length)

q_{max} = maximum filtration rate over zone being sized

1.2 = 20% blockage factor

Table 30 shows the expected capacities for typical underdrain types with 0.5% fall.

Table 30: Quick reference table for underdrain pipe capacities.

Diameter	Type	Peak flow @ 0.5%
100mm	Slotted SN16 PVC	2.5 L s^{-1}
150mm	Slotted SN16 PVC	7.3 L s^{-1}
225mm	Rigid Pipe	24 L s^{-1}
300mm	Rigid Pipe	52 L s^{-1}

4.3.3.11 Design of internal storage or saturated zone

Additional water can be stored or attenuated below the underdrains to support increased retention (through infiltration or plant uptake between events).

Additional water can be stored or attenuated below the underdrains in:

- unlined systems (where the treated flows are discharged based on the local soil conditions), or
- lined systems where:
  - the ‘reservoir’ of water that is retained between rainfall events can provide a source of water during prolonged dry spells
  - the treatment performance (in terms of nitrogen removal) can be increased.

In these cases:

- the underdrain pipe should be positioned at the base of the system.
- a riser should be used to define the normal drawdown to the nominated level (generally defined as having the top of the pipe at the base of the transition layer).

Figure 32 shows one possible arrangement for achieving an internal storage or saturated zone.

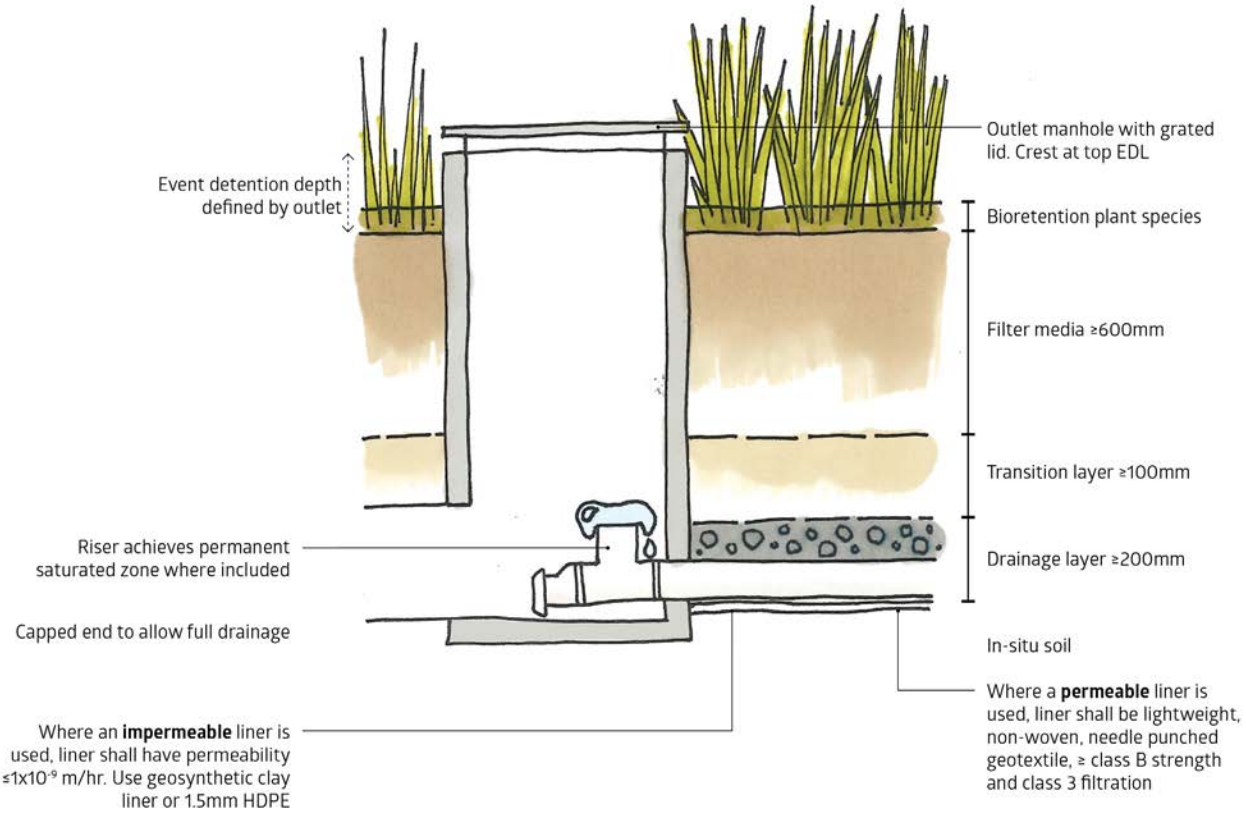


Figure 32: Example design for internal storage or saturated zone.

4.3.3.12 Planting

Vegetation plays an important role in the functional performance, ongoing maintenance and landscape amenity of bioretention devices. The selection of appropriate plants is critical to ensure optimal outcomes.

Plants in a bioretention device play a key role in the function of the system, primarily through the following characteristics:

- Extensive fibrous root mass, which provides a large surface area for the formation of algal and microbial communities to support contaminant removal. Plants with tubers or large fleshy roots are not well suited.
- Vigorous root growth (and die back) to maintain the porosity and hydraulic conductivity of the filter media and provide an ongoing organic carbon source to maintain soil health.
- Tolerant of prolonged dry periods and low moisture soils, while at the same time being able to cope with periods of inundation and saturated soils.
- Tolerant of low nutrient/organic soils to optimise treatment (in particular phosphorous removal).
- Tolerant of conditions at proposed site (ie wind, harsh sun and coastal conditions as applicable).
- Dense above ground growth to shade filter surface, to reduce temperatures and weed growth.
- Predominantly fine leafed surface growth (ie grasses and sedges) to enable water movement without obstruction to flow.
- Perennial growth, with no deciduous trees in close proximity where possible.

Key specifications for plants

The correct selection and specification of plants for bioretention systems is important, due to the harsh conditions and functional requirements. A diverse mix of species is preferable, to provide resilience to the system and enable natural selection of the species most suited to the site-specific conditions.

The following specifications must be factored into any planting plans:

- Plants must be planted at a minimum density of four plants/m^2 (planted as 0.5 L pots), with six plants/m^2 when planted as root trainers.
- Plants transplanted from elsewhere or separated from conglomerate clumps must not be planted within bioretention devices under any circumstances, as establishment of such plants will have a low success rate in the harsh conditions.
- Plants must be healthy and vigorous, with strong root structure when planted.
- Plants must not be root bound.
- Plants must ideally be planted between May–September. Where this is not practical, additional irrigation water will be required and allowance will need to be made for higher replacement planting due to high mortality.
- Plants must be fully saturated before planting and well-watered immediately after planting.
- Plants must be irrigated as required (dependent on weather), to ensure good initial growth.

Key specifications for trees

Larger trees with extensive root systems should not be planted within the footprint of the filter media in bioretention devices. This is because the bioretention needs to be reset after 15-25 years, with replacement of at least the upper layer of filter media.

If larger trees are planted, they would need to be removed during the reset. This is incompatible with intended landscape outcomes. In addition, the filter media is not optimal for tree structure or moisture retention.

Instead:

- Trees should be integrated into the landscape design on perimeters or compartmentalised separately to the filter media, with a permeable screen installed between the tree zone and filter media.
- Where trees are planted close to the filter media, they must be:
  - species with hardy characteristics , tolerant of root disturbance and potential cut back at the time of reset, or
  - provided with appropriate root guards.
- Good examples of such trees include:
  - Metrosideros species.
  - Totara.
  - Kowhai.
  - Kaikomako.
  - Putaputaweta.

Bioretention species

Species within the bioretention can be selected to provide habitat and food for lizards, invertebrates and birds. Where species are selected for habitat, there must always be nearby planting of a similar planting palette that is not within the bioretention, to enable a refuge during rainfall events.

Plant species to be used within bioretention systems must be resilient to prolonged dry periods in harsh low organic sandy soils. Species suited to use in bioretention systems in the filter media planting area include:

Oioi	Apodasmia similis
Pūrekireki, purei	Carex appressa
Pūrekireki, purei	Carex bucananii
Pūrekireki, purei	Carex dissita
Pūrekireki, purei	Carex flagelifera
Wiwi	Ficinia nodosa

Wiwi	Juncus pallidus
Hinarepe	Poa billardierei

In addition to the main “treatment species”’ within the bioretention, up to 10% of diversity species can be included. These diversity species can be included for aesthetic reasons and may be connected with nearby landscape planting. Locally indigenous species can also be used to add structure and biodiversity to the filter surface, including:

Sand Coprosma	Coprosma acerosa
Coastal Shrub Daisy	Olearia solandri
Makaka, Maukoro	Carmichaelia australis
Piripiri	Acaena pallida
Tī kōuka	Cordyline australis
Harakeke	Phormium tenax (coastal)

Perimeter batters and nearby landscaped areas can be planted with any plants suited to the site-specific conditions and the overall landscape intent. These can include:

- the species listed for the filter media
- larger shrubs and trees, as long as they do not restrict maintenance access or impede the function of the bioretention.

5 VEGETATED SWALES – TECHNICAL GUIDANCE

Urukahika Stream, Porirua. Land development has affected many natural stream systems in the Wellington region by concentrating the flow of stormwater and its contaminants into the receiving environment. The health and water quality of streams are afforded protection under the Regional Natural Resources Plan for the Wellington region. Water sensitive design is an important tool for minimising the impact on waterways of urbanisation and land development.

5.1 Introduction

This section provides technical guidance for the design of vegetated swales designed to manage and provide treatment for stormwater runoff.

5.1.1 Scope exclusions

This guideline does not cover bioretention swales or swales on grades greater than 5%.

5.1.2 Basis of design

The design methodology in this guideline is based on the method contained in contained Auckland Council's GD2017/001 and NZTA's Stormwater Treatment Standard for State Highway Infrastructure.

We have made one key amendment to the design criteria in Auckland Council's GD2017/001 for the maximum allowable water depth. This aligns the local design methodology in this guideline with criteria used in other national and international guidelines.

5.2 Vegetated swales – description

A swale is essentially a vegetation lined open channel that provides an overland flow path for stormwater runoff during rainfall events. This does not include channels that:

- retain intermittent or perennial flow (including where this is via baseflow seepage into upstream pipe network), or
- flow through areas that are water-logged and retain standing water due to elevated groundwater (sometimes referred to as 'wetland swales').

Swales are predominantly dry overland flow paths that are only engaged during rainfall and planted with species suited to the hydrological regime. It is important to understand the limited treatment processes that swales can achieve and to avoid situations where unmitigated stormwater flows can discharge to natural waterways.

5.2.1 Benefits and functions

Swales have historically been used for stormwater conveyance, mainly as roadside drains in areas without kerb and channel. Recent national and international research investigating the full stormwater management potential of swales has identified many potential additional benefits, including:

- reduced peak flow during frequent rainfall events by slowing down the discharge and increasing lag time
- increased opportunity for groundwater recharge during small frequent events through infiltration
- reduced runoff volumes (particularly from frequent minor events) through increased evapotranspiration and soil infiltration
- removal of a range of stormwater contaminants through sedimentation, physical filtration and some plant uptake.

Figure 33 shows a typical swale cross-section and main components.

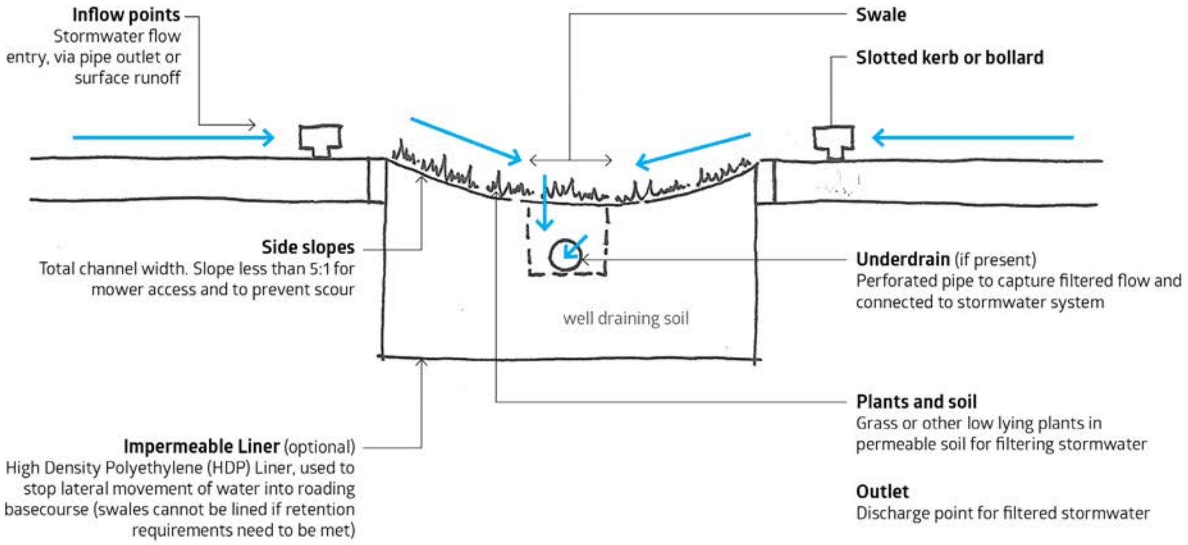


Figure 33: General cross sectional arrangement of a swale (source: Auckland Regional Council, 2011).

5.2.2 Limitations to swale use

Swales can provide good pollutant removal on an individual event basis and will provide moderate long-term pollutant removal through the filtering and sedimentation of contaminants into the upper soils and some uptake by plants. However, because swales are typically designed and constructed online to all flows, they do not provide performance comparable to other treatment devices such as constructed wetlands or bioretention systems.

This is mainly due to the incidence of peak flows (in exceedance of the water quality flowrate) remobilising accumulated contaminants and discharging these to downstream environments. Where swales are constructed on moderate slopes, the increased erosive forces can not only result in contaminant flushing, but also scour of the surface soils and progressive incision. Many roadside channels that typically do not maintain a vigorous plant community in the base are prone to such ongoing incision and scour.

Swales will provide some detention of flows (through reducing velocity) and can support retention through infiltration (where underlying soils are suitable). However, swales generally provide fewer benefits when compared to those provided by wetlands or bioretention.

In addition, several maintenance challenges have been encountered with the widespread adoption of swales in other national and international locations. These can include:

- Ingress of aggressive weed species within the channel due to the wetting/drying regime and seed material in stormwater. Unless maintained, this can result in further weed invasion and potential blockages, causing ponding between events.
- The requirement of trafficable crossings at road and/or private property intersections increases the need for proactive inspection and maintenance to avoid ongoing blockages.
- Multiple vehicle crossing points (at driveways) that increase the risks of damage due to vehicles cutting corners or attempting to park on saturated soils.
- Turbulence related scour at inlet points and culvert crossings. Unless design includes appropriate scour protection at multiple locations, it is likely that pools will progressively form along the length of the swale.
- Isolated pockets of stagnant water between events. This supports mosquito breeding habitat, without the predator species found in more biodiverse systems.
- The design of grassed systems to be mown can be challenging in prolonged periods of wet weather.

5.3 Vegetated swales – design

5.3.1 Design considerations

This section provides guidance on the key design factors that must be considered in the design of vegetated swales.

5.3.1.1 Stormwater treatment train

Based on the above limitations, swales are only supported as part of the public stormwater system where they are providing a conveyance function to be integrated with a broader landscape amenity function. This can be well suited to pre-treatment in advance of downstream devices such as wetlands and to support general community connection with water and education.

The sizing for treatment of any device placed downstream of swales should exclude 50% of the upstream catchment areas treated by swales, in addition to accounting for any contributing untreated catchment of the device.

5.3.1.2 Integration with flood management

Swales are well suited to be integrated with site wide flood flow management and overland flow, albeit with an increased risk of re-mobilisation of contaminants. In such situations:

- any proposed modelling methodology must align with Wellington Water requirements for catchment hydrology and flood management
- careful consideration must also be given to public safety, in particular any risks of entrapment against grates during infrequent flood events, where flood conveyance is within public spaces.

Where swales are used to convey flows into downstream devices (wetlands and/or bioretention), the design must include appropriately designed diversion structures to ensure that the wetland/bioretention can operate offline to peak flows. This will also require design of bypass and potentially secondary hydraulic structures to support engagement of flood detention. Refer to the Constructed Wetlands and Bioretention sections in this guideline for more information on diversion design.

5.3.1.3 Key design constraints

Based on observed challenges with swales in a range of contexts, the following constraints are currently placed on the design of swales:

- Swales must have a maximum longitudinal fall of 5%.
- The use of check dams or terraced linear swales will only be supported with the pre-approval from Wellington Water. This must include the design of check dams and scour protection to respond to the full range of potential flow conditions.
- Underdrains must be included where longitudinal fall is less than 2%.
- Bioretention swales (with prescribed filter media in sloping narrow swales) will not be supported. Bioretention systems must be based on a uniform (level) filter surface only.
- Wetland swales (with permanent water in long linear online systems) will not be supported. In many instances, wetland swales will function as constructed waterways. This can add value to developments for amenity and ecology but will typically offer limited water quality treatment due to lack of detention times.

Where swales are proposed as part of the public network, the design must align with clear design process and parameters. This will to ensure that the system is robust and resilient to a range of flow conditions, without resulting in an ongoing maintenance burden.

5.3.1.4 Geotechnical guidelines for vegetated swales

The following geotechnical guidelines in Table 31 must be applied in the design of vegetated swales if excavation is 500mm deep or greater.

Table 31: Geotechnical guidelines for the design of vegetated swales.

Can the swale alter the natural groundwater levels?	**Yes**	Possibly, however the effect is considered temporary and minor.
	No	See other questions.
Is the swale located above retained land?	**Yes**	Setback of 3x the apparent height of the retaining wall to the nearest part of the device. This setback may be able to be reduced with the advice of a geotechnical professional.
	No	See other questions
Is the swale located below retained land?	**Yes**	Setback of 3x the apparent height of the retaining wall to the nearest part of the device. This setback may be able to be reduced with the advice of a geotechnical professional.
	No	See other questions.
Is the swale on a sloping site >5^0?	**Yes**	Risks of slope failure must be considered at the earliest stage of design. Swales must not be used where infiltrating water may cause slope instability. Geotechnical investigations are needed across the entire design area to understand the underlying soils, and designs must accommodate all geotechnical constraints (such as soil instability). If the device is proposed to be placed above or below or on slope then professional geotechnical advice must be sought. A swale may only be used on slopes steeper than 14° (25% or 1V:4H) if the effects have been assessed by a geotechnical professional. If swale is at the toe of a slope, the sides of the device should be structurally sound as to replace any loss of support to the surrounding ground that would have been provided and must be fully lined. If swale is at the crest of a slope the sides of the swale must be fully lined and setback 2x the depth of the excavation from the crest.
	No	See other questions.
Is the swale adjacent to or nearby any structures or foundations (includes horizontal infrastructure)?	**Yes**	If the swale is closer than 2x its width to a structure or foundation seek professional geotechnical advice. Where swales are required to be close to structures, or to trafficked roads, structural support may be required. This can be avoided where it is possible to locate devices away from loads producing significant lateral forces.
	No	See other questions.
Is the swale near a public or private road?	**Yes**	The device should be fully lined to prevent influx of water into the road subgrade (unless the road design allows for this). The sides of the device should be structurally sound as to replace any loss of support the ground would have provided that has now been removed.
	No	See other questions.

5.3.2 Technical device sizing

This section provides guidance for the technical sizing and design of vegetated swales.

5.3.2.1 Recommended design parameters

The hydraulic retention time (HRT) of a swale is the average retention time of the water quality flow (WQF). It is the key stormwater quality objective upon which swale design is based and must be at least nine minutes. Other key design considerations are provided in Table 32 below. These include values relating to the performance of a swale when conveying peak flows up to the 10% AEP event. As noted earlier, this guideline is primarily focused on the water quality aspects of design but includes these key parameters to reduce the risk of damage to the swale.

As swale design is an iterative process, designers may need to test varying values for design elements to meet the nine minute HRT requirement and other key parameters.

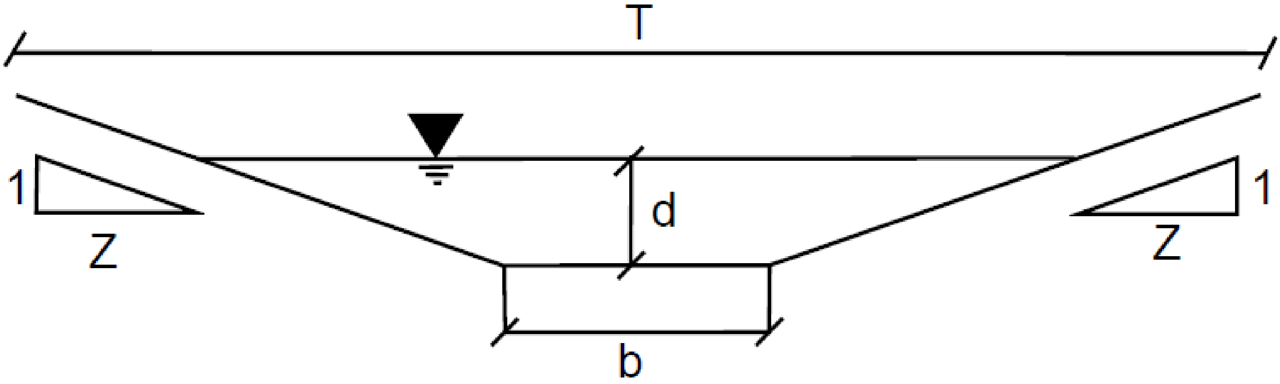
Table 32: Recommended design parameters for vegetated swales.

Parameter	Abbreviation	Dry and infiltration swales
Water Quality Flowrate	$Q_{WQF} = WQF$	Runoff from the water quality storm calculated using the rational method as per Section 2.4.
10% Annual Exceedance Probability (AEP) storm runoff	$Q_{(10\%)}$	Runoff from the 10% AEP storm calculated using the rational method with runoff coefficients as per WQF and the appropriate rainfall intensities sourced from the Regional Standard for Water Services.
Longitudinal slope	S	Swales are not suitable on slopes greater than 5%. Slopes of 5% require check dams. Swales on slopes less than 2% require an underdrain.
Hydraulic retention time	HRT	9 minutes or longer. Best design practice is to minimise high contaminant loading within the final third of swale length, given that HRT and water quality treatment in the final portion may not be attained.
Maximum velocity		For water quality storm, maximum velocity = 0.8 m/s[#] For 10% AEP storm, maximum velocity = 1.5 m/s
Water quality storm flow depth	d	Maximum of 150mm.
Water quality storm Manning's roughness	n	0.25.
10% AEP Max Depth	$D_{10\%}$	Lesser of 300mm deep or 150mm below top of swale.
10% AEP Event Manning's Roughness	$n_{10\%}$	0.03 grassed swale (mown). 0.25 vegetated swale.
Design vegetation height		150mm grassed swale. 300mm for vegetated swales.
Vegetation type		Fescue and rye for grass swales. Refer to section 5.3.3.4 for vegetated swales.
Length	L	>30m[*].
Base width	b	0.6 – 2m.

Parameter	Abbreviation	Dry and infiltration swales
Side slopes	1V:zH	1V:3H planted or 1V:5H if mowing required. Flatter where space allows.
Freeboard		Freeboard to comply with adjacent infrastructure requirements.
Under-drains		Required when swale slope <2%.
Notes: # Maximum Velocities for Q_{WQF} taken to be 0.8m/s as per Table 8.5.1.1 Basic Design Parameters for Swales, NZTA Stormwater Treatment Standard, 2010. *Shorter swale length may be used where primary purpose is conveyance and/or amenity i.e. where water quality not required or is provided by other measures.		

5.3.2.2 Cross sectional geometry

Trapezoidal channels are the most common design and are also considered to generally represent the performance of parabolic swales. While there are benefits in designing variability and diversity into swales that have a key amenity/ecology role, we recommend that all swales are designed assuming a trapezoidal cross section (Figure 34). The equation for cross sectional area and hydraulic radius are given in Equation 10 and 11 below.



D = Total swale depth (m)

T = Swale width (m)

d = Water depth (m)

b = Base width (m)

z = Side slopes (1V:zH)

$T = b + 2Dz$

Figure 34: Cross-section of trapezoidal swale design.

Equation 10: Calculation of the swale cross-sectional area.

$$A = bd + zd^2$$

Where

A = Cross sectional area of channel (m^2)

b = Base width of channel (m)

d = Water depth (m)

z = Side slope (1V:zH)

Equation 11: Calculation of the swale hydraulic radius.

$$R = \frac{A}{P_{wetted}} = \frac{A}{b + 2d\sqrt{z^2 + 1}}$$

Where

R = Hydraulic radius of channel (m)

P_{Wetted} = Wetted perimeter (m)

A = Cross sectional area of channel (m^2)

b = Base width of channel

d = Water depth (m)

z = Side slope (1V:zH)

The geometry of the swale is primarily associated with maintenance requirements. The side slopes need to be gentle enough and the bases wide enough to allow full access for mowing equipment (where required). Where mowing access cannot be provided, swales should be planted with species that do not require mowing and do not obstruct the flow of stormwater. Recommended side slopes and base widths are provided above in Table 32 above. Swale slopes should be no steeper than 1V:5H if mowing is required, or flatter if space allows.

5.3.2.3 Manning's equation for base width, velocity and flowrate

Manning's Equation is generally used in swale design to estimate the flow characteristics in the swale. The equation is used in an iterative process to produce swale design characteristics such as length, longitudinal slope, geometry, flow depth and HRT within a given range.

Manning's Equation is an empirical equation that predicts the velocity of water flowing through an open channel based on the physical characteristics of the channel. Manning's Equation can be expressed as:

Equation 12: Manning's Equation

$$Q = \frac{1}{n} A R^{2/3} S^{1/2}$$

Where

Q = Flowrate in the swale (m^3/s)

n = Manning's roughness coefficient

A = Cross sectional area of swale (m^2)

R = Hydraulic radius of swale (m)

S = Longitudinal slope (m/m)

The key variable in the equation is the Manning's Roughness coefficient 'n', which is used as a measure of the surface roughness provided by the vegetation in the swale. Table 32 gives Manning's roughness coefficients for different flow conditions and vegetation.

By employing a commonly used assumption about the depth and width ratios of a trapezoidal channel, the depth of a trapezoid can be used to approximate the hydraulic radius. By assuming a flow depth, substituting flow depth for the hydraulic radius, and using Equation 10 for the cross-sectional area, the base width of a trapezoidal swale can be calculated using Equation 13.

Equation 13: Calculation of swale base width

$$b = \frac{Q_{WQF}\, n}{d^{5/3} S^{1/2}} - zd$$

Where

b = Base width (m)

Q_{WQF} = Water Quality Flowrate (WQF) (m^3/s)

n = Manning's roughness coefficient

d = Water depth (m)

S = Longitudinal slope (m/m)

z = Side slope (1V:zH)

Velocity of flow is a function of the flow area, slope and frictional resistance of the vegetation. The following expression of Manning's Equation is used to calculate the velocity of flow in a swale.

Equation 14: Calculation of swale velocity.

$$v_m = \frac{1}{n} R^{2/3} S^{1/2}$$

Where

v_m = Flow velocity using Manning's equation (m/s)

R = Hydraulic radius (m)

S = Longitudinal slope (m/m)

n = Manning's roughness coefficient

The swale flow rate can then be estimated using the following equation:

Equation 15: Calculation of swale flowrate.

$$Q_m = v_m A$$

Where

Q_m = Flow rate (m^3/s)

v_m = Flow velocity (m/s)

A = Cross-sectional area of the swale (m^2)

5.3.2.4 Length and longitudinal slope

The minimum length for a swale is generally accepted to be 30m, which is related to the relationship between HRT and flow velocity. Swales <30m length may be designed in circumstances where small catchments enable performance parameters (HRT, flow velocity etc) to be met, or for systems where conveyance is the only design objective (and no water quality performance is attributed).

Longitudinal slope has several effects on swale performance. In general terms, the greater the slope, the faster the water will pass through the swale and the shorter the HRT will be. The ideal range for longitudinal slope is 1% to 3% (see Table 33), with under drains required when the swale slope is less than 2%, and the maximum recommended slope being 5%.

Swales steeper than 5% must not be supported due to the risk of ongoing scour. Wellington Water does not generally support the use of check dams and longitudinal steps to "reduce" the slope. This is due to the tendency for ponded water in the long term and risks associated with scour, piping and collapse around dam structures.

5.3.2.5 Velocity

In many cases, swales designed to meet the target HRT during the water quality design event will require velocities substantially lower than the maximum allowable velocity. Where this cannot be achieved, the swale will not be considered to provide any water quality improvements.

The maximum velocity for flow within a swale is defined to optimise settlement, avoid erosion, scour, and resuspension of deposited sediment. The maximum allowable velocity during the water quality event is 0.8m/s as per Table 8.5.1.1 of NZTA's Stormwater Treatment Standard 2010.

The maximum flow velocity for the 10% AEP storm event is 1.5 m/s as per Table 8.5.1.1 of NZTA Stormwater Standard 2010. For events over the 10% AEP design flow, rules for overland flow path (OLFP) and flood detention will apply in accordance with the Regional Standard for Water Services.

5.3.2.6 Hydraulic retention time

An HRT of 9 minutes for the WQF is required. HRT is used as an indicator of the amount of deposition that will occur over the length of the swale. It is important to take into consideration the reduced treatment efficacy of the final flow length of the swale; high contaminant sources should not flow into the final third of the swale. The HRT of a swale can be calculated using Equation 16.

Equation 16: Calculation of the hydraulic retention time.

$$HRT = \frac{L_{eff}}{60v}$$

Where

HRT = Hydraulic retention time (min)

L_{eff} = Effective swale length (m)

v = Flow velocity corresponding to the WQF (m/s).

5.3.2.7 Effective swale length

Swales can have single or multiple inlets. Multiple inlets can either be from discrete lateral inflow points along the length (e.g. multiple piped inlets) or fully distributed sheet flow (e.g. flush kerbs). Where a swale has lateral entry, all or part of the inflow will enter along the sides of the swale, generally at an angle perpendicular to the swale centre line. Lateral entries are common along roads, highways and in car parking lots, where the swale is constructed along one boundary of the catchment. Where a swale has one inlet the Effective Length is the actual length of the swale from inlet to end (i.e. $L_{eff} = L$).

Where a swale has more than one inlet, the average HRT for the entire swale must be a minimum of 9 minutes or longer. The average HRT for multiple inlets can be estimated using the effective swale length (L_{eff}) calculation, Equation 17.

Equation 17: Calculation of the effective swale length.

$$L_{eff} = \frac{L_1Q_1 + L_2Q_2 + \ldots + L_nQ_n}{Q_T}$$

Where

L_{eff} = Effective swale length (m)

L_n = Length of swale from inlet n to end of swale (m)

Q_n = Design flow rate into swale from inlet n (m^3/s)

Q_T = Total flow rate into swale from all inlets (m^3/s)

Where a continuous lateral inflow occurs i.e. distributed sheet flow, the length to the end of the swale is taken from the midpoint of the length of continuous lateral contribution (i.e. if a swale is 100m long and there is lateral inflow throughout then the effective length is 50m).

5.3.2.8 Conveyance of 10% AEP event

The swale must also convey the 10% AEP rainfall event. Increased runoff from the 10% AEP will result in higher and faster flows through the swale. Having calculated the flowrate for the 10% AEP event ($Q_{10\%}$), the depth of flow through the swale ($d_{10\%}$) can be found by solving for "d" using Manning's Equation below (Equation 18). All swale parameters (b, z and S) will remain constant from the Q_{WQF} example with the exception of Manning's roughness coefficient (n). See Table 33 for Manning's and $Q_{10\%}$ values.

Equation 18: Calculation of flow depth for 10% AEP event

$$Q_{10\%} = \frac{1}{n}\left(\frac{bd + zd^2}{b + 2d\sqrt{z^2 + 1}}\right)^{2/3} S^{1/2}\left(bd + zd^2\right)$$

Where

$Q_{10\%}$ = 10% AEP flowrate calculated using the rational method (m³/s)

n = Manning's roughness coefficient

b = Base width of swale (m)

d = Flow depth in 10% AEP event (m)

S = Longitudinal slope (m/m)

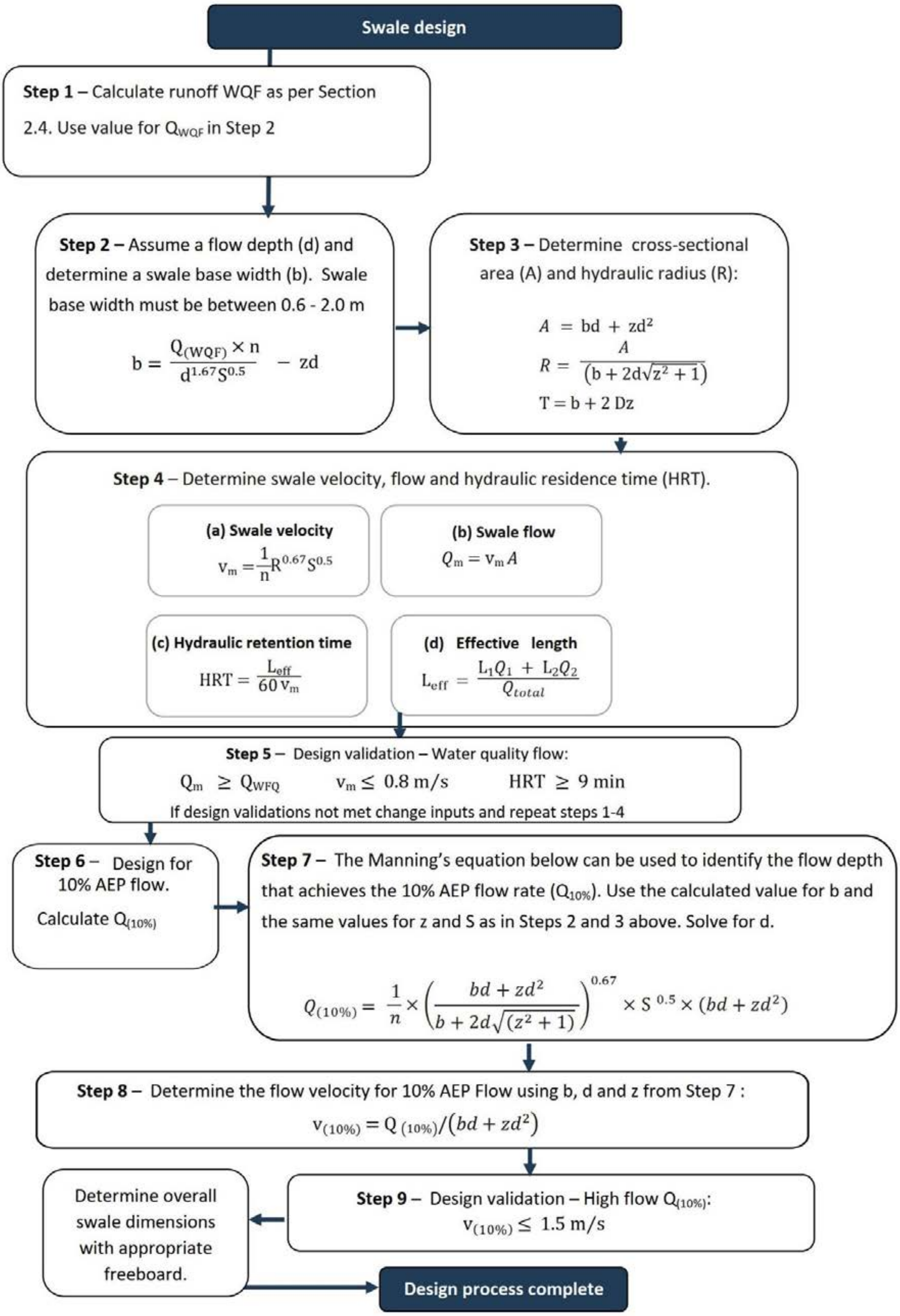
z = Side slope (1V:zH)

5.3.2.9 Summary of swale hydraulic design process

The process for sizing a vegetated swale is iterative. An initial 'working' geometry is selected, then tested against parameters for swale performance including maximum velocities, retention time for water quality treatment, and conveyance capacity for larger flows.

Select initial geometry for the swale including: longitudinal slope (S), side slope (z) and length (L) based on site layout. Select a Manning's coefficient (n). Assume a flow depth (d). Using Manning's Equation, solve to find an approximate base width (b). Acceptable ranges for S, z, L, n, d and b are provided in Table 32. Check against maximum velocity and hydraulic retention time (treatment) for the water quality storm. Adjust flow depth and/or geometry if necessary and repeat the process until geometry allows design parameters to be met. Check that geometry also meets depth and velocity parameters for the high flow, 10% AEP event.

Figure 35: Swale design flow chart for water quality treatment design



Professional judgement should be used to adjust inputs to meet the design parameters for flow rate, velocity and HRT. The adjustments should be informed by experience and knowledge of what is practical at the site. Table 33 provides some general design iteration suggestions.

Table 33: Suggested design iterations

Failed Design check	Suggested changes to design inputs
$Q_m < Q_{WQF}$	Increase design water depth. Increase base width. Increase side slopes, keeping the top width the same. Decrease catchment area draining to the swale.
Velocity through swale is greater than 0.8 m/s (for Q_{WQF}) or 1.5 m/s (for $Q_{10\%}$)	Decrease longitudinal slope. Increase cross-sectional area. Decrease catchment area draining to swale.
HRT < 9mins	Decrease velocity (as per above) Increase actual swale length. Increase effective swale length by diverting higher proportion of flows to the head of the swale.

5.3.3 Component design

This section provides guidance on the design of the components of a vegetated swale.

5.3.3.1 Inlet design

Swale inlets need to be suitably designed to prevent localised scour that could be caused by high inflow velocities, particularly where this results in concentrated inflows perpendicular to the main flow direction. The design of appropriate erosion protection is dependent on the flow characteristics of the incoming pipe or overland flow path (refer to Auckland Council's technical report, TR 2013/0181, for details on erosion protection). Consideration must be given to the likely deposition of sediments in close proximity to the inlets and provision made for maintenance access to address this. Where distributed flows enter the swale via flush kerb or similar, care must be taken to ensure that the edges are not blocked over time. This will typically be achieved with a 50–100mm drop along the top edge, considered planting and possible use of a gravel or rock buffer strip.

5.3.3.2 Underdrains

Where swale longitudinal slopes are below 2%, particularly in areas where local soils have poor infiltration capacity, underdrains are recommended to prevent stagnation and saturation of the swale bed. These drains should be constructed along the centreline of the swale underneath the base of the swale topsoil bed. The drains should comprise slotted drainage coil (unsleeved) within a trench of drainage aggregate constructed at the same grade as the swale (0.5% minimum).

In applications where infiltration into underlying low permeability soils is required to reduce stormwater volumes or recharge groundwater (particularly with sensitive receiving waterways), the use of gravel filled trenches beneath the swale soils may be considered with agreement from Wellington Water.

5.3.3.3 Soil media preparation

Swales constructed in areas with high infiltration capacity soils are able to provide improved stormwater quality and quantity benefits. For sites with low infiltration capacity soils, it can be advantageous to construct swales using compost amended topsoil to improve shallow infiltration.

Where site topsoils are of poor quality, we recommend that the swale bed be prepared using compost amended topsoil to provide an improved media, to promote vegetation establishment. The following method is recommended.

1. Grade the swale bed to 200-300mm below the finished level (the top of the finished swale should sit below the adjacent ground level to promote even sheet flow into the device along the perimeter).
2. Loosen compacted subsoils by ripping to 300mm. If uncompacted, scarify subsoil 100mm below the grade.
3. Spread high quality topsoil mix (from landscape supplier and suitable for horticultural purpose), which will settle to ~200mm finished bed depth. Do not compact, but the first lift should be ripped to mix with the subsoil.
4. A minimum of 200mm finished soil bed depth should be established.

5.3.3.4 Planting

Uniform vegetation cover in grassed swales is important to prevent short circuiting by diffusing flow over the full width of the swale. The selection of appropriate vegetation should also consider the landscape objectives for the site, potential biodiversity benefits, and ecological connections with any connected remnant waterways. Partial shade from harsh mid-summer sunlight is important to maintain moisture levels within swales and ensure that elevated water temperature does not impact receiving waterways.

Vegetation species with large stems or trunks, or placing signs, lamp posts etc. within the bed of the swale should be avoided to prevent the generation of preferential flow paths, which can lead to accelerated erosion of the swale bed. Plants that may impact visual sightlines for vehicles or pedestrians are to be avoided.

Suitable species list

Species suited to vegetated swales include:

- Carex dipsacea
- Carex gaudichaudiana
- Carex maorica
- Carex virgata
- Ficinia nodosa
- Juncus edgariae
- Acaena anserinifolia
- Leptinella dioica
- Lobelia angulata
- Libertia ixiodes
- Muehlenbeckia axillaris.

6 PERVIOUS PAVING – TECHNICAL GUIDANCE

Kaiwharawhara Stream, Wellington Harbour. The mouth of Kaiwharawhara Stream is the only estuarine environment on the southern coast of Wellington Harbour. The water quality in Kaiwharawhara Stream has been degraded by stormwater and wastewater overflows. Kaiwharawhara Stream is home to a number of native fish species, and efforts are being made to monitor and restore the fish habitat for future generations.

6.1 Introduction

This section provides guidance for the design of passive pervious paving (capturing only rainfall which falls directly onto the paving surface) with total infiltration for stormwater retention and treatment.

6.1.1 Scope exclusions

This guideline is intended for the design of pervious paving systems in low traffic situations on residential property. This guideline does not cover active pervious paving or installations that require underdrainage (that is, partial infiltration or no filtration).

For applications outside of residential property, the principles remain much the same, however designers must:

- receive specialist advice where pervious paving is proposed for areas outside of private residential boundaries, such as carparking in private retail/commercial sites or public carparking
- seek this advice from a suitably qualified pavement design engineer and may be subject to approval by the relevant council's roading engineer.

6.1.2 Basis of design

The design methodology in this guideline is based on the method contained in Auckland Council's GD2017/001 and CIRA's The SuDS Manual 2015 with amendments to bring the design criteria in line with other national guidelines and product specifications.

6.2 Pervious paving – description

Pervious paving is the general term used to describe a constructed hard surface that allows water to pass through to the underlying soil layers. It can be used to reduce runoff and flooding; and help to replenish groundwater.

Pervious paving systems can be considered passive or active:

- A passive system only captures rain that falls on the pervious paving area itself. Since the definition of impervious surface specifically excludes pervious paving, a passive system can be used in developments to meet relevant impervious surface thresholds so that stormwater consenting requirements are not triggered.
- An active system is one that is designed to capture runoff from nearby impervious areas in addition to rain that falls on the pervious paving area. Active systems need to be carefully designed to have high enough surface infiltration rates and storage volumes to accommodate the additional runoff from the nearby catchment area/s, in accordance with hydrologic mitigation requirements.

Due to its potential to become clogged with sediments, pervious paving is not considered appropriate for high traffic areas, or in areas subject to heavy sediment loads. Since the aggregate is subject to structural loading, its use is also limited to areas where there is: light vehicle traffic, little/no acceleration, little/no vehicle turning, and no heavy goods vehicles.

Treatment processes provided by pervious paving are limited to filtration and sedimentation (with solids settling into the pore spaces of the pavement). Pervious paving, as specified in this section, is unsuitable for treating areas with high contaminant generating activities.

6.2.1 Benefits and functions

Pervious paving works by enabling rainfall to percolate through a pervious surface and infiltrate into the underlying ground. This helps to avoid the potential impacts of increased imperviousness, while still supporting uses such as vehicle movements or paved landscapes. Pervious paving benefits include:

- at source stormwater management
- elimination of runoff during small to moderate events and reduction of runoff in large events
- retention through infiltration to groundwater
- water quality treatment through sediment entrapment (and any attached contaminants such as metals)

While capturing sediment can provide benefits from a treatment perspective, it is noted that maintenance is required to maintain pavement porosity. Maintenance will vary depending on the amount of sediments but may require infrequent clearance through specialist cleaning. Due to the risk of clogging, it is vital to avoid overloading the surface through sediment laden runoff from nearby areas (such as during building) or concentrated loads through activities such as car washing.

Pervious paving does not address issues with dissolved contaminants (such as nutrients and/or dissolved metals) that can be passed through to receiving environments depending on hydrogeology. These contaminants are typically lower in a domestic low trafficked context such as driveways and patios.

The effectiveness of pervious paving is directly related to the hydraulic conductivity of the in-situ soils, as the overall performance is limited by this rather than the flow through the paving itself. Due to the need to construct pervious paving on a solid and robust subgrade, it is important to:

- ensure that design is based on the as-constructed ground conditions allowing for compaction, sub base and any imported engineered fill
- always make provision for surface runoff from pervious paving, to accommodate flows from events that exceed the infiltration capacity or where blockage in the paving system itself restricts through flow. This overland flow must be managed in accordance with standard stormwater design practice as per the Regional Standard for Water Services.

6.2.2 Main components

The design and construction of pervious paving includes several critical layers and functional components. Due to the typical variable live loads (cars and or pedestrians), these layers are especially important to ensure that the system is fit for purpose over its design life.

6.2.2.1 Surface stormwater drainage

Surface drainage needs to be provided to take excess flows in case of blockage or extreme rainfall events that exceed the infiltration capacity of the paving. All surface stormwater drainage must comply with Regional Standard for Water Services and other relevant New Zealand standards.

6.2.2.2 Edge restraints

Solid edge restraints such as concrete nibs should be provided around all edges of permeable block paving to resist lateral movement of the pavers. Edge restraints are generally not required for continuously laid surfaces (for example porous concrete) that depend on subsoil conditions and expected live load conditions. Advice on edge restraints must be sought from a suitably qualified pavement engineer where uncertainty exists.

6.2.2.3 Surfacing

There are two distinct types of pervious paving surfaces that can be described as either permeable or porous depending on the method of water ingress.

Permeable surfaces consist of impervious units with permeable gaps or spaces which allow water to infiltrate into the underlying layers as shown in Figure 35 below. Examples of permeable surfaces include concrete block pavers and concrete grid pavers.

Porous surfaces allow water to pass through pores or voids within the surface itself and are generally continuously laid as shown in Figure 36 below. Porous surfaces include porous concrete, porous asphalt, resin bound aggregates and porous concrete blocks.

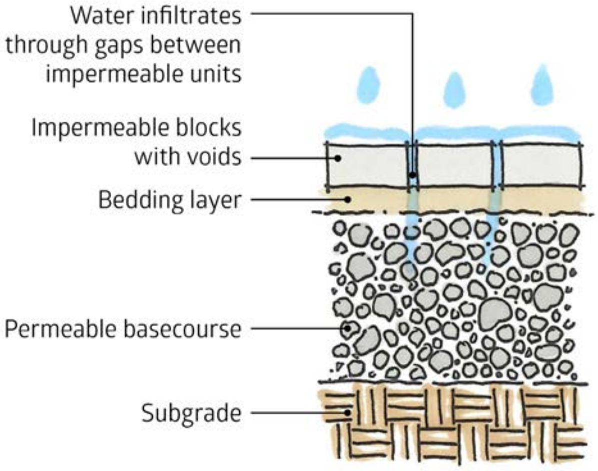


Figure 35: Permeable surface schematic.

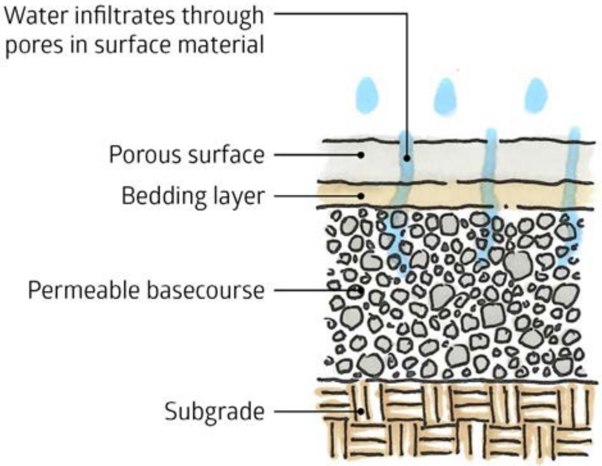


Figure 36: Porous surface schematic.

6.2.2.4 Bedding layer and jointing material

The bedding layer provides a stable platform on which to construct the pervious surface layer and should reduce the risk of clogging. The thickness of the bedding layer depends on the intended application and type of paving system selected. The jointing material is the granular fill used in the joints between individual pavers and is generally the same material as for the bedding layer. For permeable or porous concrete block paving, these components provide a mechanical connection between individual units.

6.2.2.5 Geogrids

Geogrids are a structural grid with large holes (<10mm) that provide structural reinforcement to the pavement layers. Geogrids can be specified by manufacturers for use in pervious paving and are acceptable for use where required.

6.2.2.6 Permeable basecourse

The permeable basecourse layer generally consists of a coarse-graded, clean, durable aggregate and provides a solid foundation on which to construct the overlying layers. This layer requires a high voids ratio and must not break down with repeated wetting and drying over the life of the paving. The basecourse can also be referred to as a 'storage medium' as the voids can provide storage for runoff once it has infiltrated into this layer. Alternatives such as plastic void formers may also be used for this layer. If plastic void formers are used, loading and cover requirements must be checked to ensure they are fit for the proposed use. See Section 6.3.7 for a permeable basecourse specification.

6.2.2.7 Subgrade

The subgrade is the underlying in-situ soil on which the pervious paving is to be constructed. Care must be taken to avoid excessive compaction of the subgrade that could reduce the infiltration capacity of the soil.

Verification of the saturated hydraulic conductivity of the subgrade is required before the placement of any overlying materials.

- This verification must be based on the final subgrade level following excavation.
- This verification is to be provided through an in-situ double ring infiltration test. A minimum of one test per 100m^2 of pervious paving area must be completed by a suitably qualified professional.
- Tests completed before the final excavation will be required for design purposes but must be verified once the final subgrade is formed and before the placement of any overlying materials.

6.3 Pervious paving – design

This section provides guidance for the technical design of pervious paving.

6.3.1 Site suitability

The first step in the design process is to determine the suitability of pervious paving for the site location and characteristics. Table 34 sets out the recommended design limitations for pervious paving installations.

Table 34: Pervious paving design limitations.

Parameter	Limitation
Subgrade	Saturated Californian Bearing Ration (CBR) should not be less than 3%.
Slope	Maximum allowable slope of 12%.
Land-use	Pervious paving should not be located downstream of high-sediment generating activities.
Stability	Pervious paving must not be used where infiltrating water may cause slope instability.
Ground water	Pervious paving must not be used where seasonal high groundwater table is less than 0.6m from the invert of the pervious paving system.
Contaminated land	Contaminated land may pose a risk to the environment if exfiltration of surface runoff occurs. Other contaminated land areas may have contaminated groundwater that should not be allowed into the stormwater network. If either of these conditions are present at a site, the pervious paving must not be used.
Structures	Pervious paving placed within 3m of a structure must have the nearby vertical surface lined. The impervious liner should be a minimum 0.25mm thick polypropylene.
Impervious liner	Pervious paving placed adjacent to roadways should have an impervious liner placed on the vertical side adjacent to the roadway or around the nearby road subdrain. The impervious liner should be a minimum 0.25mm thick polypropylene.
Location	Nearby impervious surfaces must drain away from any pervious paving area and have provision for separate stormwater management, independently of pervious paving. Allowance for surface runoff from pervious paving should be made to accommodate flows from events that exceed the infiltration capacity or where blockage in the paving system itself restricts through-flow.

6.3.2 Paving system selection

The pervious paving system to be used must be appropriate for the intended end use of the site.

Five paving systems and their suitability for various applications are presented in Table 35. These paving systems are only suitable for use in private residential properties and commercial carparks. Where these systems are proposed in other applications, the designer must demonstrate that the selected system is suited to the site-specific loadings.

The five paving systems in Table 35 are:

- **Permeable blocks:** Paving blocks that are constructed from porous material. Water can move through the blocks and through the bedding sand between the blocks.
- **Porous concrete:** A no fines concrete that has pores to allow the passage of water through the concrete layer. Cement levels in the mix are increased to provide a similar strength to normal concrete surfaces.
- **Porous asphalt:** Contains pores to allow the passage of water through the layer.
- **Resin bound aggregates:** Polished stones that are bound together with resin. This product can have a wide range of aesthetic finishes due to aggregate colour or resin.
- **Concrete pavers:** Pavers with significant gaps in their layout that are filled with free-draining soil to allow the passage of water into the in-situ ground.

Table 35: Possible applications for different pervious paving surfaces.

Application	**Pervious paving surface type**				
	Permeable blocks	Porous concrete	Porous asphalt	Resin bound aggregates	Concrete pavers
Patios and pedestrian areas	✓	✓	✓	✓	✓
Driveways <5°	✓	✓	✓	×	✓
Driveways >5°	✓	✓	☑	×	×
Parking Areas	✓	✓	✓	☑	✓
Note: ✓= Suitable with correct design, ☑= Possibly suitable with pavement engineering input, × = not suitable					

The paving surface selected must have an infiltration rate greater than 120 mm/hour over the life-time of the device, with a minimum initial rate of 1,200mm/hr at installation (safety factor of 10x to account for potential clogging of the paving surface) (ARC, GD01 2017). Many pervious paving surfaces can provide even higher infiltration rates.

Once a suitable paving surface type is selected, an assessment of the subgrade must be made. Assessment must include verification of the saturated hydraulic conductivity of the in-situ subgrade using a double ring infiltrometer by a suitably qualified person.

The saturated hydraulic conductivity for the in-situ subgrade must be ≥15mm/hr.

Pervious paving as specified in this Guideline is a passive device so it is only capturing rainfall that falls directly on the paving surface (no additional catchment). The design rainfall intensity for the WQF in the Wellington Region is 10mm/hr (see Section 2.4.3). Therefore, neither the paving surface, basecourse (see Section 6.3.7 for specified permeability), nor subgrade will limit the capture or total infiltration of the water quality design storm.

6.3.3 Surface specification

6.3.3.1 Concrete paving blocks (permeable and porous)

The pavers should be a minimum of 80mm thick and comply with the requirements of NZS 3116: 2002 Concrete and Segmental and Flagstone Paving. The paver type should comply with the requirements in NZ 3116 for Application 2, residential driveways, light traffic.

Pavers should be laid in a herringbone pattern at 45° to traffic flow. Joint widths must be sufficient to meet the infiltration requirements, provided that the joints are not wider than the D_{95} of the jointing sand plus 3mm.

6.3.3.2 Porous asphalt

Porous asphalt surfaces used in pervious pavement systems should generally be the same as standard open graded porous asphalt typically used on New Zealand roads. The materials and mix design should meet the requirements of TNZ P/11 (TNZ, 2007). It is suggested that an 80/100 penetration grade be used.

The percent of binder should be between 5.5% and 6%, based on the total weight of the pavement. The lower limit is to assure adequately thick layers of asphalt around the stones, and the upper limit is to prevent the mix from draining asphalt during transport. Polymer modified binders should be used.

6.3.3.3 Porous concrete

On completion of 7-day curing, the porous concrete must be tested for a baseline infiltration rate using ASTM C1701 testing methodology. This must be completed in a separate 1m by 1m square of concrete constructed in an identical method to the final surface.

6.3.3.4 Resin bound aggregates

Pervious resin bound aggregate surfacing are generally proprietary products installed by specialist installers. The manufacturer's specifications should be followed for these surfaces.

6.3.4 Geotechnical guidelines for pervious paving

There are geotechnical constraints to be considered in the design of pervious paving.

The following geotechnical guidelines in Table 36 below apply where non-pervious pavements are replaced with pervious pavements (hence there would be a resulting change in water infiltration levels).

Table 36: Geotechnical guidelines for the design of pervious paving.

Is the pervious pavement on a slope	**Yes**	Pervious paving must not be used where infiltrating water may cause slope instability.
	No	See other questions.
Is the pervious pavement adjacent to or nearby any structures or foundations?	**Yes**	The pervious pavement must be designed as to not compromise any damp proof membranes.
	No	See other questions.
Is the pervious pavement near a road (i.e. road widening or share pathway)?	**Yes**	The pervious pavement should prevent influx of water into the road subgrade (unless the road design allows for this).
	No	See other questions.
Is the pervious pavement above a retaining wall?	**Yes**	Setback of 3x the apparent height of the retaining wall to the nearest part of the device. This setback may be able to be reduced with the advice of a geotechnical professional or if the retaining wall drainage has been designed to accommodate additional flow from a pervious pavement.
	No	See other questions.
Is the pervious pavement below a retaining wall?	**Yes**	Setback of 3x the apparent height of the retaining wall to the nearest part of the device. This setback may be able to be reduced with the advice of a geotechnical professional.
	No	See other questions.

6.3.5 Structural design

The paving thickness required to ensure adequate structural strength is related to the design traffic loading and the load bearing properties of the materials selected for the various layers (surfacing, bedding, basecourse and subgrade).

The manufacturer's specifications for structural design, including layer thicknesses and material performance specifications should be followed to ensure the particular product:

- performs as intended by the manufacturer
- satisfies warranty requirements.

6.3.6 Bedding layer and jointing material specification

For porous paving, use NZS 3116: 2002 Concrete and Segmental and Flagstone Paving Sand Category (<5 mm diameter grain size). For permeable paving, use 2–7mm diameter chips.

6.3.7 Permeable basecourse specification

Permeable basecourse should comply with all the requirements of NZTA's Specification for basecourse TNZ M/4 (2006), except for the particle size distribution which should meet the recommended grading envelope defined in Table 37, when tested according to Test 3.8.1 Wet Sieving Test as per AS/NZS 4407:1991 Methods of sampling and testing road aggregates.

Table 37: Recommended particle size distribution for permeable basecourse aggregate (ARC, GD01 2017).

Sieve size (mm)	Upper limit (%)	Lower limit (%)
19.0	100	100
13.2	95	100
9.5	75	90
6.0	50	75
4.75	30	50
2.36	0	10

The permeable basecourse must be clean, washed aggregate and should have a minimum porosity of 30% at the compacted density. It should have a minimum permeability of 0.03m/s.

The pavement layers should be compacted in layers of uniform thickness not exceeding 150mm to ensure that the maximum density is achieved for the particular aggregate type and grading, without crushing the individual particles.

6.3.8 Testing

Random samples of all granular materials used (eg bedding, jointing, and basecourse) should be taken and tested to verify compliance with the design parameters (ie grading, voids ratio and compacted permeability).

7 APPENDICES

View of Mana Island from mouth of Taupō Stream, Plimmerton. Taupō Stream has cultural value to Ngāti Rangatira Toa. Taupō Swamp is located in the upper reaches of Taupō Stream and is nationally significant for its ecological value. Taupō catchment has been identified for increased urban growth. Water sensitive design can play an important role in protecting this environment as urban growth intensifies in the surrounding area.

7.1 Appendix A – maintenance tables

The following tables provide a list of potential maintenance activities, along with likely frequencies. These tables:

- are broken down into routine maintenance activities (which would occur on a yearly or less frequent cycle) and corrective maintenance activities (which would occur every few years or so), and
- have been adapted from the Activating WSUD in NZ report on "Understanding Costs and Maintenance of WSUD in New Zealand" (Ira and Simcock, 2019).

Wetlands Maintenance

Wetlands: Routine maintenance	Frequency (per year)
Routine general maintenance (tree and shrub trimming/lifting, mowing access track*, maintaining healthy vegetation cover, fertilising, removing litter including dog pooh, includes plant and weed assessment	4
Removing debris (eg litter, dead vegetation) from outlet and inlet/forebay structures, reinstating any scour/erosion	4
Inspections (Ducks, QA, inspection of embankments, spillways, outfalls, overall functioning of facility, integrity of fences and stakes if present)	1
Scheduled Routine Mechanical Maintenance (pumps, outlets, removing mosquito breeding areas)	1
Make good from vandalism (trim /replace plants, remove graffiti)	1
Weed management	2 – late spring and summer to prevent seeding
Aquatic weed management	1
Additional visits for initial aftercare of Plants (for first 2 to 4 years until "completion" standard is achieved), includes initial tree form prune and canopy lift to retain dense groundcover **	2

*mowing relates to access tracks only (other mowing is associated with non-functional components of the wetland system).

**intensity of initial aftercare more dependent on initial weed pressure, plant density and growth rates, i.e. high intensity/frequency where weed pressure is high and growth rates slow.

Wetlands: Corrective maintenance	Frequency (number of years)
Corrective structural maintenance (repairs to pumps, concrete components, dam embankments/baffles, erosion)	10
Replacement of parts (grates, trash screens)	20
Replanting the wetland zone*	50
Desilting and disposal of sediment from forebay*	5
Desilting and disposal of sediment from main pond*	50

*Actual frequencies are dependent on the sediment and contaminant load being captured and removed by the wetland.

Raingarden maintenance

Raingarden: Routine maintenance	Frequency (per year)
Routine landscape maintenance Undertaking general landscaping inspections, removing litter, maintaining vegetation, weeding: · Maintaining vegetation in functional status is ensuring plants are trimmed to ensure inflows, overflows and outflows are clear to the extent design capacity is maintained. · It includes up to 5% replanting or remulching (especially at inlets, corners, and places damaged by cars/road workers and other people). Includes checks to determine if irrigation is needed during unusual droughts (10-20% AEP drought events). · It does not include trimming vegetation infringing on footpaths or roads more than once per annum due to poor plant selection or placement, or higher amenity. · Inspections (for debris, inlets, outlets, overflows, integrity of biofilter) and clearance of debris at inlets.	4
Trees Excluded from raingarden	N/A
Functional drainage maintenance · Flush out drainage Note - Biofilter infiltration rate/performance is best scheduled after rainfalls that are large enough to create ponding (usually 25mm events). Inlet, overflow and outlet clearance should also be assessed as part of routine landscape maintenance.	2
Traffic control costs Where traffic management is needed · Traffic lane closure (static or mobile works) · Road closure setup costs – static closures · Road closure setup costs – mobile closures	As needed
Initial aftercare of plants (first 3 years)	4

Raingarden: Corrective maintenance	**Frequency (number of years)**
Additional landscaping/maintenance may be required due to poor design of rain gardens. This can have a dramatic effect on maintenance cost and usually relates to: · Removal of deciduous leaves from inlets/overflows and preventing deciduous leaves smothering groundcover vegetation. · Additional trimming of vegetation around signs, lights, rubbish bins or other infrastructure placed in raingarden (services and signage should not be placed in raingardens). · Surface removal of silt/fine sediment/concrete cutting wash and deposits washed into the raingarden that will impact either infiltration or plant performance. · Removing dead vegetation due to ponding because of incorrect rain garden mix/over-compaction of mix so that infiltration rates are too low, or blocked underdrainage/poor outlet design. · Forking of surface to relieve compaction and restore permeability after damage from vehicles or foot traffic that lowers infiltration rates; usually also requires mulching to provide protective cushion while plants recover. · Fixing erosion of outlets due to poor slope control or undersized rain gardens. · Road closures for ‘centre road’ rain garden maintenance.	As needed
Condition assessment/performance audit.	5
Removal and disposal of sediments (including replacement with new media) + cartage[*]	20
Complete replanting[*]	10
Major maintenance of drainage system, eg replacement of parts	50
Traffic control costs Where traffic management is needed: · Traffic lane closure (static or mobile works). · Road closure setup costs – static closures. · Road closure setup costs – mobile closures.	As needed
Council/network operator inspections – cost to private rain gardens.	1

[*] Actual frequencies are dependent on the sediment and contaminant load being captured and removed by the rain garden.

Swale maintenance

Swales: Routine maintenance	Frequency (per year)
Routine general maintenance for grass swale (mowing, edge-spraying or trimming, weeding)	10
Routine general maintenance for planted swale in perennial vegetation (maintaining healthy vegetation cover, weeding, edge trimming, mulch replacement)	4
Routine general maintenance – as above but needs road or lane closures to allow for maintenance (for major arterial roads use this item)	4
Inspections (inlets for scour, ruts and preferential flow, debris, outlets, integrity of swale/dispersed flow) and removing debris/litter and sediment (eg from inlet or overflow structures)	4
Deciduous trees – sweep and remove leaves	2
Make good following vandalism (bollards, repair of barriers, re-staking trees) Note: where trees are in grassed swales use protection against weed whackers to avoid trunk damage	1

Swales: Corrective maintenance	Frequency (number of years)
Maintaining even, dispersed flow - removing accumulated sediment; regrading, filling and decompaction to remove tyre ruts or scoured areas*	5
Disposal of sediment to landfill*	25
Re-grassing (assume turf mat or coir/wool seeded mats used given swale is online)	25
Replanting – plugs with coir/wool erosion mat (high amenity has nine plugs/m^2 or larger plants, low amenity has four plugs/m^2 with no large plants)	25
Replanting/ grassing (where road closures are required)	25
Minor repairs to inlet or outlet structures	10
Replacement of bollards (discontinuous kerbing)	10
Replacement of underdrain	25

*Actual frequencies are dependent on the sediment and contaminant load being captured and removed by the swale.

Pervious paving maintenance

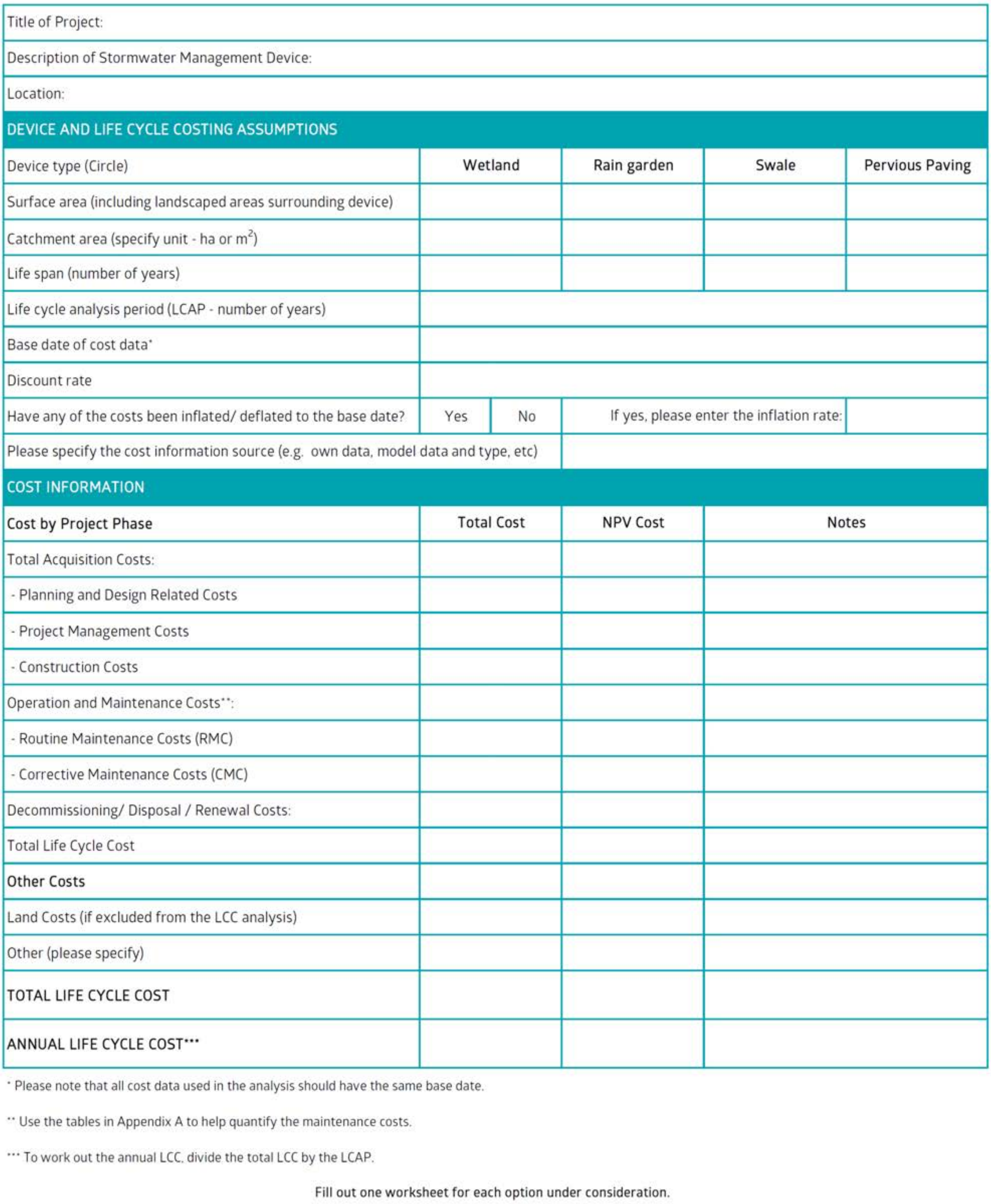
Pervious paving: Routine maintenance	Frequency (per year)
Inspections and regular cleaning of organic sediments and debris. Includes yearly clean for weed/moss control if not part of design. Note to ensure inspections coincide with storm events to check drainage function	2–6
Minor repairs	0.5–1

Pervious paving: Corrective maintenance	Frequency (number of years)*
Cleanout sediment, oils, etc and removal of top layer of stone and re-establishment (top up joint chip or sand between pavers). Note – need to suck out material not water blast it deeper!	10
Top-up of low fines joint mix	10
Disposal of unsuitables	10
Replacement of permeable pavers (if necessary)	50
Uplift pavers, replace sand and bedding	50
Asset inspection (check if still in place and not paved over)	5

*For larger installations such as parking lots use a lower frequency and a higher cost.

7.2 Appendix B – LCC record example sheet

This example sheet to record a LCC analysis can be provided upon request in spreadsheet format.



Title of Project:				
Description of Stormwater Management Device:				
Location:				
DEVICE AND LIFE CYCLE COSTING ASSUMPTIONS				
Device type (Circle)	Wetland	Rain garden	Swale	Pervious Paving
Surface area (including landscaped areas surrounding device)				
Catchment area (specify unit - ha or m^2)				
Life span (number of years)				
Life cycle analysis period (LCAP - number of years)				
Base date of cost data*				
Discount rate				
Have any of the costs been inflated/ deflated to the base date?	Yes No	If yes, please enter the inflation rate:		
Please specify the cost information source (e.g. own data, model data and type, etc)				
COST INFORMATION				
Cost by Project Phase	**Total Cost**	**NPV Cost**	**Notes**	
Total Acquisition Costs:				
- Planning and Design Related Costs				
- Project Management Costs				
- Construction Costs				
Operation and Maintenance Costs**:				
- Routine Maintenance Costs (RMC)				
- Corrective Maintenance Costs (CMC)				
Decommissioning/ Disposal / Renewal Costs:				
Total Life Cycle Cost				
Other Costs				
Land Costs (if excluded from the LCC analysis)				
Other (please specify)				
TOTAL LIFE CYCLE COST				
ANNUAL LIFE CYCLE COST***				

* Please note that all cost data used in the analysis should have the same base date.

** Use the tables in Appendix A to help quantify the maintenance costs.

*** To work out the annual LCC, divide the total LCC by the LCAP.

Fill out one worksheet for each option under consideration.

8 BIBLIOGRAPHY

The diving platform at Wellington waterfront. This platform is located at the mouth of Waimapihi Stream which is now contained in a large stormwater culvert. Following heavy rain, the diving pool can be unsafe for swimming due to contamination arriving from the nearby stormwater culvert. Water quality must be improved to ensure the city's residents can enjoy a connection to its water now and into the future.

This section provides a list of references which have informed these guidelines. These references draw on a combination of recent and ongoing practical experience with the implementation of WSD and substantial applied scientific research into the performance of specific devices.

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