LANDSCAPE AND ECOLOGY VALUES WITHIN STORMWATER MANAGEMENT

Auckland Regional Council
TE RAUHĪTANGA TAIAO

TECHNICAL REPORT – FIRST EDITION.

Reviewed by:

Name: Hayden Easton

Position: Team Leader
Stormwater Action Team

Organisation: Auckland Regional Council

Date: 3 August 2010

Approved for ARC Publication by:

Name: Paul Metcalf

Position: Group Manager
Environmental Programmes

Organisation: Auckland Regional Council

Date: 9 August 2010

Recommended Citation:
Lewis, M.; Simcock, R.; Davidson, G.; Bull, L. (2010). Landscape and Ecology Values within Stormwater Management. Prepared by Boffa Miskell for Auckland Regional Council. Auckland Regional Council Technical Report TR2009/083

CONTENTS

INTRODUCTION

The Auckland Regional Council (ARC) Technical Publication (TP)10, was published in 2003 to "demonstrate the ARC's preferred design approaches for structural stormwater management devices".

Chapter 14 of the document focused on landscape values, including aspects of economic value, public access, visual mitigation (screening), and recommendations for the establishment of plants. Other sections of the document discussed function of plants, and landscape maintenance for individual devices.

In terms of ecology, TP10's focus was aquatic resource protection. This was one of three technical objectives for TP10. Specific guidance was provided to maintain the physical structure of receiving environments while promoting practices conducive to healthy ecosystems.

This document is a review of ARC's TP 10, with specific regard to promoting values for landscape and ecology in the design of stormwater management devices. The document's structure is based on three levels of specificity, provided as principles, specifications, and recommendations (refer figure 1).

1. The principles section introduces systems and material elements that contribute to landscape and ecology values.
2. The specifications provide a general technical overview to inform soil, planting, and pest control for stormwater management devices.
3. The third section includes recommendations for landscape and ecology for each of the stormwater management devices. Recommendations include a table to guide habitat enhancement, a detailed plant schedule, and an operation and maintenance programme.

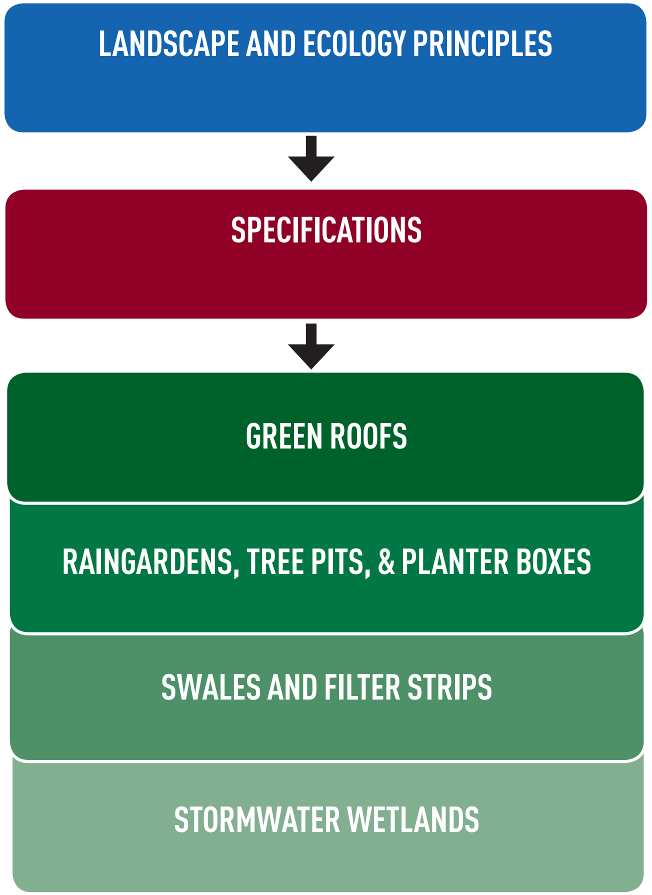


Figure 1: The report outline indicates three levels of specificity to apply landscape and ecology to stormwater management devices

1.0 LANDSCAPE AND ECOLOGY PRINCIPLES

Where stormwater management devices provide for landscape and ecological function they are more likely to show improved operation and reduced maintenance. There is also potential for ancillary benefits, including enhanced natural character values, landscape amenity values, and corresponding economic values.

The following principles recognise opportunities to achieve multiple objectives for ecology, landscape, and stormwater quality/quantity. This can be achieved through specific treatment of the construction elements of soils, plants, and structures, and through optimising the synergistic benefits of these elements in combined systems (refer figure 2).

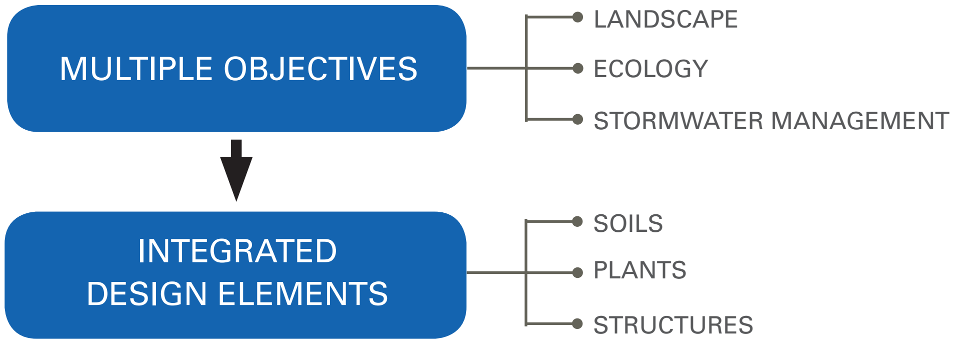


Figure 2: Principles to inform stormwater management devices for landscape and ecological function

The principles and the recommendations that follow were determined through a literature review, with reference to national, regional and local planning provisions, and from the contributions of an inter-disciplinary panel:

LITERATURE REVIEW

- Review of documents relating to SUDS, WSUD, LIUDD, LID etc from the US, UK, Australia, and New Zealand specifically for landscape and ecology elements that optimise stormwater device performance or ancillary benefits.
- Literature relevant to individual treatment devices for swales and filterstrips, raingardens and tree pits, wetlands and ponds, and greenroofs.

PLANNING PROVISIONS

- Reference to existing ARC stormwater documents.
- Supporting regional plans and national policy statements.
- Drawn from the review of 2nd generation district plans.
- Referencing Transit Authority stormwater management guidelines.

INTER-DISCIPLINARY PANEL

- Coauthorship and review of relevant areas by freshwater and terrestrial ecologists, landscape planners, water engineers, landscape architects, and plant, water quality, and soil scientists.

1.1 PROVIDE FOR MULTIPLE OBJECTIVES

Stormwater represents a resource in the landscape, providing irrigation and entrained nutrients to soil, plants, and aquatic habitats. Water is also a dynamic force, contributing to a sense of place through its elemental relationship with other media: landform, plants and structures.

(A) LANDSCAPE

A landscape-driven design extends beyond mitigation planting, to provide inherent values for a stormwater management device. If devices are constructed with landscape amenity and function in mind then they are more likely to become a permanent, well maintained feature of development, as landowners are more likely to take pride and stewardship over these facilities.

- **Protection of dominant character elements and significant sites** –Existing features, such as landform, water courses, wetlands, rock outcrops, feature trees or cultural/ heritage elements provide for strong integration with the site, and a sense of place and permanence. They should be incorporated or referenced as a design element within stormwater management devices wherever practicable.
- **Spatial experience** – Space is determined by enclosing agents, (plants, water, landform, and structure). The height and density of the enclosure determines the experience of the space (refer figure 3). Space can also be defined by a central object such as water. Stormwater ponds and green roofs have inherent spatial qualities within determinable boundaries. Planter boxes, swales, raingardens etc are more likely to represent the edge or transition between landscape spaces.
- **Spatial sequence** – Stormwater flows through a site from open expanses, to constrained gullies, a dynamic and evolving passage, with mystery and open views, active and passive spaces. In this way, a spatial sequence can be a legibile narrative in the landscape and provide interpretation for stormwater processes and landscape typologies.

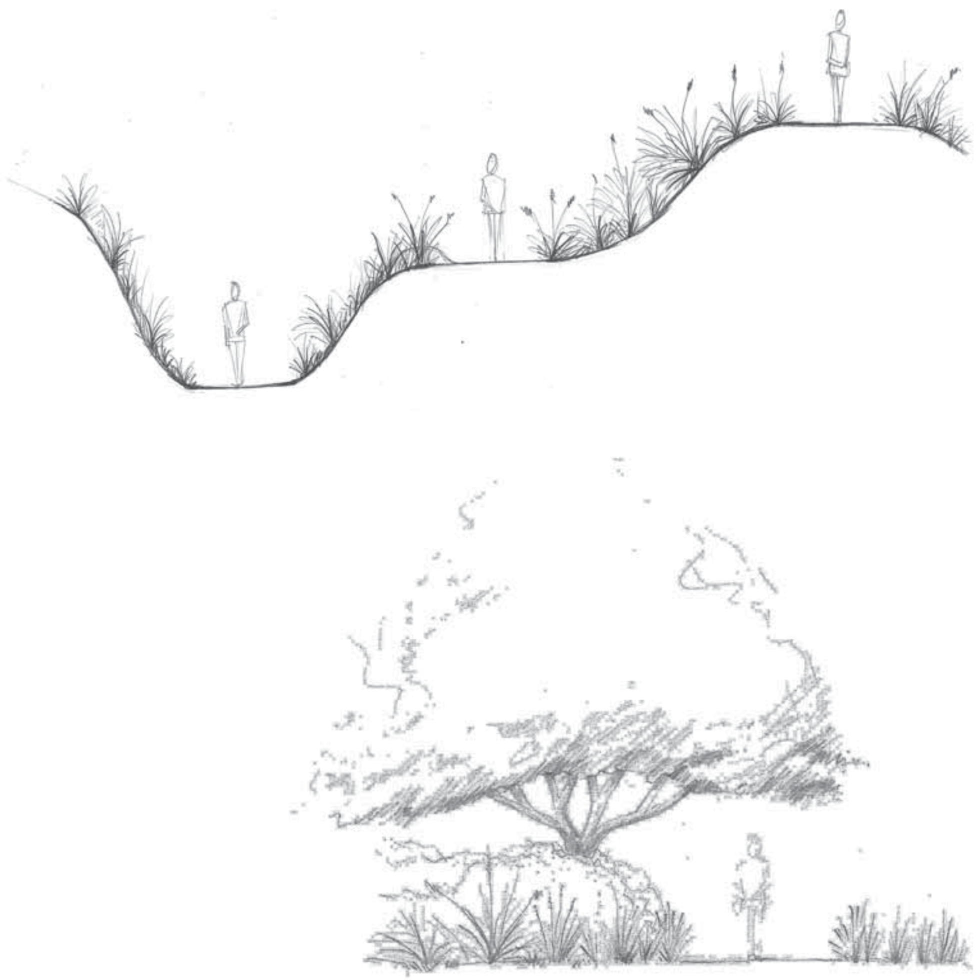


Figure 3: Variations of spatial enclosure

Figure 4: Well maintained and accessible stormwater devices provide a public space that discourages criminal activity

CRIME PREVENTION THROUGH ENVIRONMENTAL DESIGN

The Ministry of Justice guidelines for "Crime Prevention through Environmental Design" (CPTED) sets out seven qualities for well-designed, safer places. The principles are as follows (MoJ 2005):

1. Access: Safe movement and connections - Stormwater management devices to consider sightlines, and pedestrian choices to avoid criminal activity.
2. Surveillance and sightlines: See and be seen - Stormwater devices with appropriate planting heights and densities to retain sightlines and allow for passive surveillance.
3. Layout: Clear and logical orientation - Stormwater devices to work within the legible patterns of the development.
4. Activity mix: Eyes on the street - Stormwater devices to encourage passive recreation and public spaces to maintain surveillance.
5. Sense of ownership: Showing a space is cared for - Devices selected and located to maximize the landscape amenity of public spaces.
6. Quality environments: Well-designed, managed and maintained environments Stormwater management devices to provide a well-kept appearance for the neighbourhood with reduced ongoing maintenance requirements.
7. Physical protection: Use active security measures - Stormwater devices to encourage active use of appropriate areas and limit access to sensitive environments or private areas.

CPTED principles should be considered in relation to the location of stormwater management devices and their relationship with pedestrian routes. Devices that are well maintained can deter crime through the appearance of an invested and vigilant community.

- **Edges and Transitions** – Transitions are a means to integrate stormwater devices into their landscape context. For example plant species may extend from a stormwater wetland into adjacent streetscape planting. The footpath from the streetscape may extend into the stormwater wetland as boardwalk access. Edges for devices may also be abrupt, such as mow strips or sharp grasses to exclude access and to define maintenance and safety boundaries.
- **Openness or refuge** – The quality of a space can be impacted by exposure to climate and openness to public scrutiny. Sometimes views are desirable or visibility for safety is important, at other times shelter and privacy are more appropriate.
- **Public-private transition** – Public access and gathering spaces are important for community interaction. Likewise private spaces offer relief from public view. Raingardens, swales and green walls can provide buffers and visible cues to separate public and private realms while integrating landscape elements.
- **Education and Interpretation** – A community that perceives the existence of the water will often take responsibility for its condition. This can be informed through interpretive design of stormwater management systems and processes.
- **Tikanga Maori** – Design of water systems should acknowledge and potentially interpret values of Tangata Whenua including favoured plant varieties for cultural harvest, potential food sources, kaitiakitanga (stewardship), and mauri (life force/spiritual health).
- **Economics** – A number of studies demonstrate positive benefits for property values abutting well-designed water features. There is also inherent economic gain in natural capital (environmental goods and services).
- **Maintenance** – Design work should be undertaken in consultation with maintenance staff to provide for natural systems that self maintain.

TIKANGA MAORI VALUES FOR STORMWATER

Water can be described in at least five determinable states by maori, Waiora (water in its most 'pure' form); Waimaori (water for consumption); Waimate (water that has lost its mauri and is no longer able to sustain life); Waikino (water that is dangerous, such as rapids); and Waitai (seawater, the surf or the tide) (Douglas 1984).

Stormwater starts as rainfall (Waiora) but is transformed into Waikino once it flows over impervious surfaces, or makes contact with pesticides, fertilizers, pathogens and other potential pollutants. The contamination or degradation of water has the effect of diminishing the mauri of receiving waters. Thus, discharging stormwater (Waikino) into clear water (freshwater or seawater) is an example of unnatural mixing of mauri (Douglas 1984).

Potential management practices include those provided in Waitakere City's Comprehensive Urban Stormwater Action Strategy (WCC 2000):

- A holistic approach to resource management.
- Protection of habitats of edible plants and native marine life which are traditional sources of food for local Maori.
- Restoring a buffer of native vegetation alongside waterways.
- Water conservation.
- Avoiding mixing waters from different sources.
- Treating stormwater (restoring its mauri) by passing it through land before it is released into natural waterways.

(B) ECOLOGY

Stormwater management devices ultimately afford some level of protection to receiving environments, such as streams and estuaries, by affecting the quality and quantity for stormwater. However, there are also opportunities to enhance natural systems and habitat within stormwater management devices.

Ecology is essentially the relationship between organisms and their environment. Ecology represents equilibrium between biotic and abiotic elements, systems and individuals. Stormwater devices will always be affected by seasons, life cycles, and successional phases which require forward-thinking designs.

Figure 5: New Zealand Scaup

- **Protection of existing ecological communities** – The best means to provide for ecological values on a site is to protect the systems already present or those with the greatest potential for restoration. This includes hydrological systems such as aquifers and steep slopes, and isolated wetlands and springs.
- **Soil conservation** – Survey existing soils in order to isolate soils that are vulnerable to compaction, and set up soil mixing controls to optimise drainage properties for stockpiled and re-spread topsoils (discussed in further detail in 2.0 Landscape Specifications).
- **Plant Diversity** – Wherever practical, plant materials delivered to a site should be eco-sourced materials extracted as seed from remnant vegetation as close as possible to the site, and from a similar ecotone (a similar environment in terms of climate and elevation). Multiple plants should be sourced with varying phenotypes (physical variations). This will increase the gene pool for cross-pollination and provide for a resilient plant community.
- **Structural diversity** – Habitat niches exist at a variety of structural levels within a plant community, from root zones and litter layers, through herbaceous plants, understorey shrubs, canopy plants, and emergent trees (refer figure 6). It is possible to introduce materials to optimise habitat diversity for invertebrates, lizards, birds and bats e.g. snags (dead upright trees), logs, rocks, and leaf-litter.
- **Hydrological diversity** – Variable aquatic conditions provide for diverse life cycle stages of aquatic fauna. This may include cool pools, oxygenating riffles, refugia, soft and rocky substrates, and organic food sources. It is also important to consider rarer communities that dwell at the hydrological edges of floodplains, wetland margins and the hyporeic (groundwater) zone.
- **Biosecurity**– The management of invasive species in stormwater devices is best achieved through a maintenance regime involving integrated systems for pest control, utilising competitive plant selection (with appropriate spacing), natural succession processes, and allowing for effective buffer zones and/or interior habitat to prevent weed incursions.

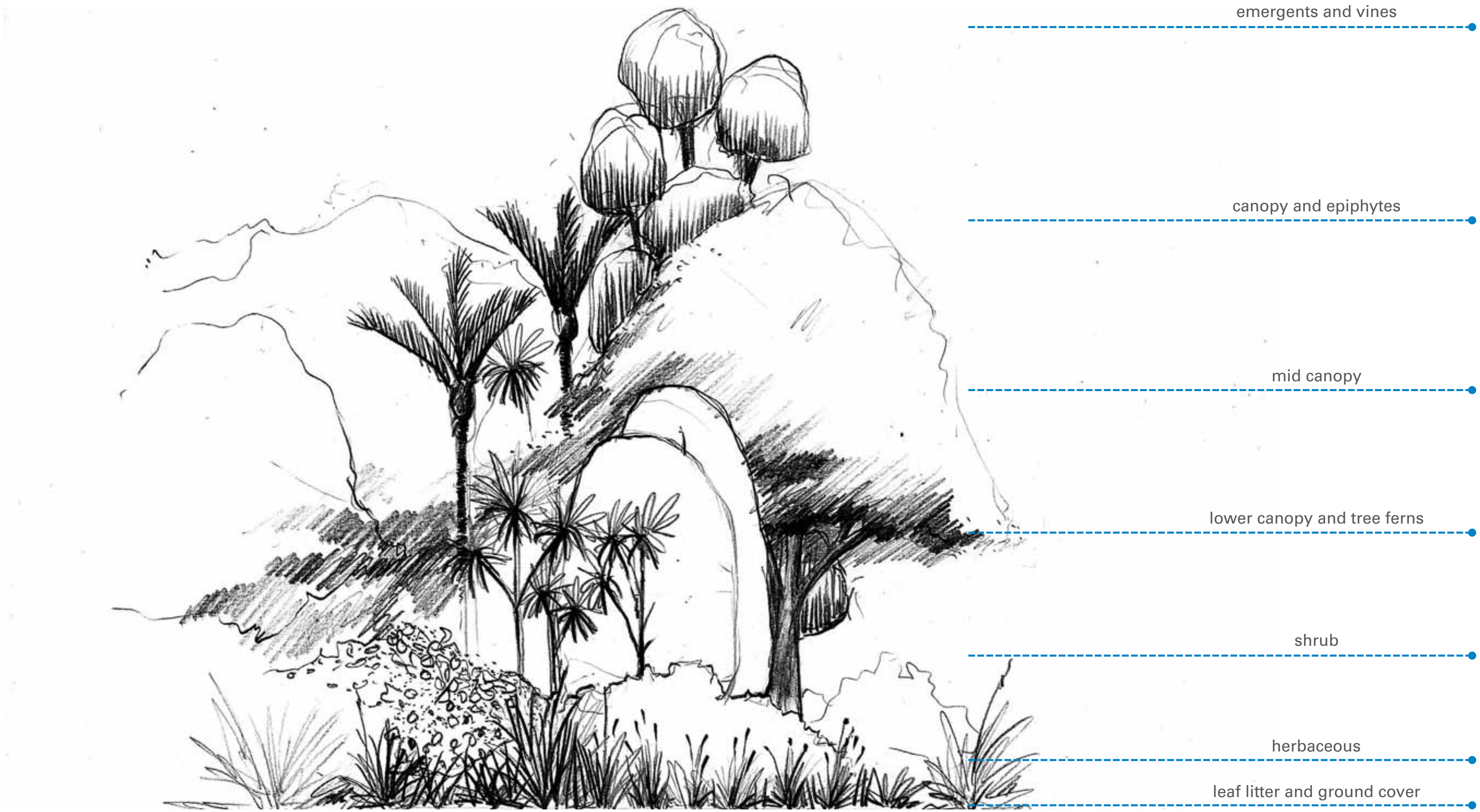


Figure 6: Structural diversity of a plant community providing diverse habitats, microclimates, and food sources

- **Landscape Ecology** – Landscape ecology has many definitions, but is generally understood as the interrelationship of size, shape, and connecting elements for habitat systems. Linkages between habitat areas are important to allow the drift of individuals and genetic material for resident populations. Linkages can be established by movement corridors and/or 'stepping stones' of supporting habitat across the landscape. This applies to birds, lizards, fish and invertebrates across their life cycles.

  Stormwater devices may need to establish a micro-climate to support plant communities. Maximising the core area of habitat forms interior conditions suited for specialised habitats and reduces the potential for weed invasion.

- **Cycles: Season, life, and succession** – Temporal changes will affect the operations and maintenance of stormwater management devices. This includes seasonal growth rates and abundance, recruitment of new individuals, and succession to different plant communities.

- **Construction techniques** – Avoid or minimise works that will affect the 'receiving environment', especially during breeding periods.

- **Ancillary Benefits** – Look to take advantage of ancillary environmental services such as moderation of dust, noise, heat, and light. This will improve habitat for local fauna as well as humans.

Figure 7: Ecological systems within park environments (Michael's Ave. Reserve, Auckland) and integrated within institutional open space (Kristen High School, Auckland)

(C) STORMWATER MANAGEMENT

The treatment performance of stormwater management devices can be improved through the optimisation of natural systems and processes and their potential to attenuate and treat stormwater, and metabolise and transform pollutants. These processes, which occur at the plant-soil-water interface, are physical, chemical and biotic in nature.

- Sedimentation and filtration – Sedimentation and filtration are physical processes to remove particles and their associated contaminants from stormwater. Specific planting types at appropriate densities will slow down and filter overland flows. Likewise, a diverse leaf litter (with accompanying physical structure) can attenuate and filter flows.
- Shade/solar requirements – It is important to balance the water quality functions provided by dense low stature planting with the shading properties of shrubs and larger trees. Both of these functions can be provided with appropriate spacing and species selection of canopy trees.
- Slope stabilisation – Plant root systems have a cohesive strength to bind soil particles to prevent surficial erosion and slumping. Once plants are established they can stabilise soils for steep banks, wetland margins and overland flow paths.
- Microbial processes – Microbial processes occur at the interface of plant roots and soil media to intercept, metabolise and sometimes transform a range of pollutants. Plant roots provide a medium and a source of oxygen for microbial processes to occur.
- Plant uptake – Plants utilise nutrients found in stormwater as a growth medium. They also take up metals, organics, and other 'contaminants' to be utilised by the plants, stored as a by-product in specialised cells, or transformed through enzymatic action. Plant litter can re-introduce stored contaminants when decomposing, and therefore

Figure 8: Concrete gaskets contain stands of raupo, which are a highly effective plant for the removal of sediment from stormwater, but are often likely to spread and dominate wetland areas

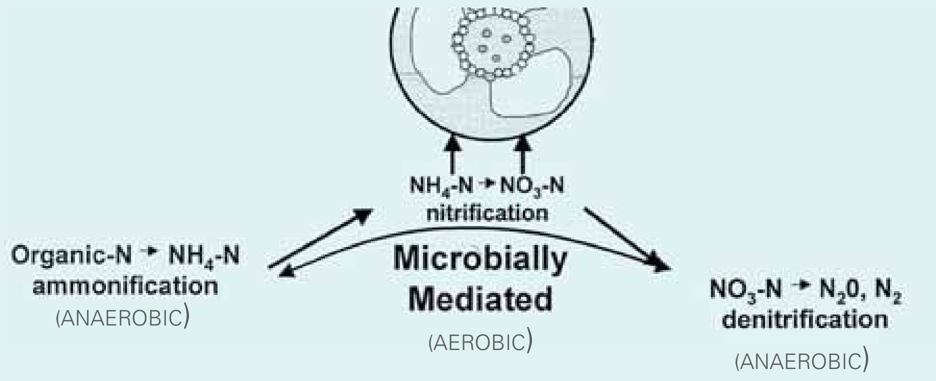
coppicing, pruning, and off-site composting of this material may sometimes be required.

- **Adsorption** - Adsorption is a chemical process that removes heavy metals and phosphorus in the upper soil horizons. Dissolved metals and phosphorus are attracted to soil particles by charge. The introduction of fresh leaf litter or compost can improve this process.
- **Evapo-transpiration and groundwater recharge** – Plants reduce stormwater volumes through evapo-transpiration. Infiltration is also possible through capture in the plant canopy, direction to stem-flow, and percolation through root pores and porous soils.
- **Balance landscape with stormwater objectives** – It is important to provide for landscape amenity and ecology values without compromising the function of a stormwater device. For example, designs should avoid large stature vegetation at entry and outlet points and trees with extensive root systems above underground infrastructure. Habitat should also be balanced against water treatment objectives e.g. reducing fly-zones and grass strips to prevent an over abundance of waterfowl.
- **Balance engineering with landscape objectives** – Stormwater devices can provide for enhanced ecology and landscape values by designing flow-rates, margins and batter-slopes to optimise ecological buffers and diverse plant communities. Structures can be designed in such a way to provide opportunities for planting, fish passage, and even habitat structure.
- **Buffer from potential contamination** – Where possible, stormwater devices can provide a secondary benefit to the treatment of stormwater by acting as a buffer to the receiving environment and/or a sacrificial system in the event of a contaminant spill.

THE PROCESSES FOR DENITRIFICATION

Wetland processes play a role in the global cycles of carbon, nitrogen, and sulphur by transforming them and releasing them into the atmosphere. It is the presence of air spaces within the stem and roots (known as aerenchyma) that allow aquatic macrophytes to exchange gases between the atmosphere and sediment. Oxygen is transported through the aerenchyma tissue into the root zone to provide a combination of aerobic and anaerobic zones. Denitrification is the major pathway for nitrogen loss from aquatic sediments to the atmosphere. Denitrification is composed of the following three processes:

1. Ammonification is a one-way reaction in which organisms break down amino acids and produce ammonia (NH_3).
2. Nitrification is the process in which ammonia is oxidized to nitrite and nitrate, yielding energy for decomposer organisms.
3. Denitrification is the process in which nitrates are reduced to gaseous nitrogen. This process is used by facultative anaerobes.



1.2 INTEGRATED DESIGN ELEMENTS

Elements used to construct and operate stormwater management devices are examined in the sections that follow to provide for landscape and ecology objectives. Significant benefits are possible for landscape, ecology, and stormwater mangement if designs consider these elements both singularly and in combinant systems.

(A) LANDFORM

Landform is the primary means to shape spaces and direct the flow of water. Soils are important determinants of land-use potential, the subterranean and surface water flows for a catchment, and expected sediment loading in stormwater.

Figure 9: Charles Jencks Landform. Image source: http://www.flickr.com/photos/rich_ford/2959085545/

- Micro-grading – One of the least promoted practices of stormwater management is micro-grading, even though it sits at a fundamental level of stormwater management. Micro-grading focuses on individual spaces such as car parks and house lots. Subtle, rolling slope-changes act to disperse surface flows and thereby reduce velocity and erosion potential. This also optimises the potential for above ground detention and infiltration in open space areas. Micro-grading requires detailed design work with increased drafting time, yet it utilises the whole site for stormwater management, facilitates treatment trains, increases passive stormwater treatment and 'time of concentration', and accordingly reduces the need for reticulated systems. Micro-grading can also provide for subtle and organic landforms.
- Soils – The categorisation of soil classes identifies potential areas for groundwater recharge and flooding, erosion issues, and media for plant growth. Soils information informs the site layout, dictates earthworks and protects good soils from mixing and vulnerable soils from compaction. In Auckland soil classes can change over a distance of only tens of metres across the surface.
- Biotechnical stabilisation – Biotechnical treatments are a combination of 'hard' (e.g. riprap), and 'soft' (e.g. geotextile soil lift) measures which stabilise bare earth to allow plants to establish. Plant roots have cohesive properties that bind soils as well as tensile strength to prevent shearing of slopes. Biotechnical approaches utilise the stabilisation properties of plants to reduce structural measures such as retaining walls, gabions etc. Biotechnical measures can be applied on steep slopes to prevent surficial erosion and slumping, within channels to prevent erosion by water flow, and on banks subject to wet and dry cycles (refer figure 10).

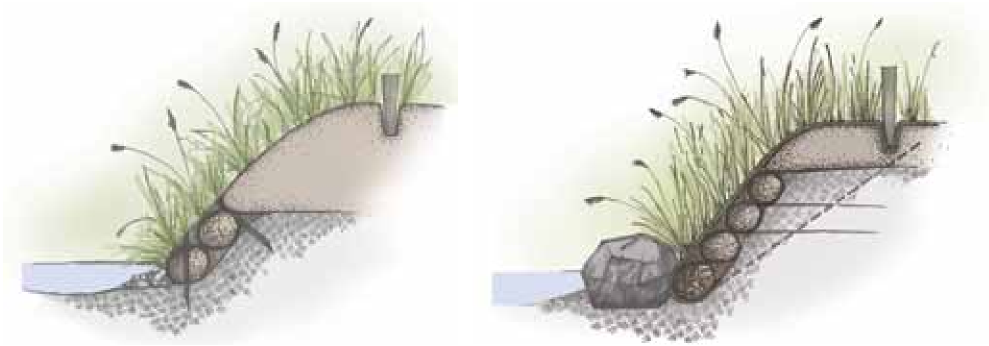


Figure 10: Examples of biotechnical measures for stream bank stabilisation

(B) PLANTING

Ideally planting can deliver multiple benefits to stormwater devices, including stormwater management function, enhancement of ecological values, and shaping of landscape function and amenity.

- Aesthetics – Planting aesthetics can be understood as a function of form, pattern, texture, tone, and colour (refer figure 12).
- Planting form – Planting form refers to the stature and growth pattern of individual specimens through seasonal variations. Manipulated forms can direct the viewer's gaze, frame views, form a screen, or orient a space.
- Planting pattern – Plant patterns refer to the repetition of form (refer figure 13).
- Planting texture – Texture represents a perception change from fine to coarse, and is normally determined by planting types and distance. Texture affects the sensation of plants (soft and voluminous vs. stark and harsh). Low and spreading plants tend to soften straight edges, spikey plants add verticality to the centre of planting beds or contrast with fine-grained plants such as grasses to add visual diversity, wispy or smoky textured plants can fill spaces between contrasting plants.
- Planting tone – Tone relates to darkness and light in terms of planting density and foliage. Tone is important to provide for light and shadow, to accentuate space and edges, and to design for shade.

Image source Landezine, http://www.landezine.com/?p=2337

Figure 11: Drifts of plant colours and textures provide for diverse landscapes

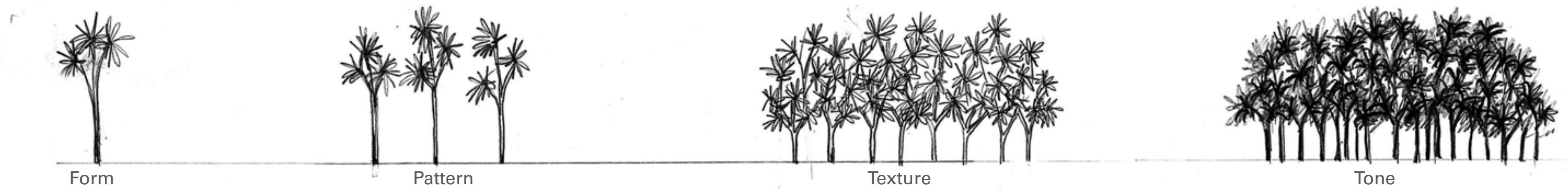


Figure 12: Planting aesthetics can be modified by repetition of individual plant qualities

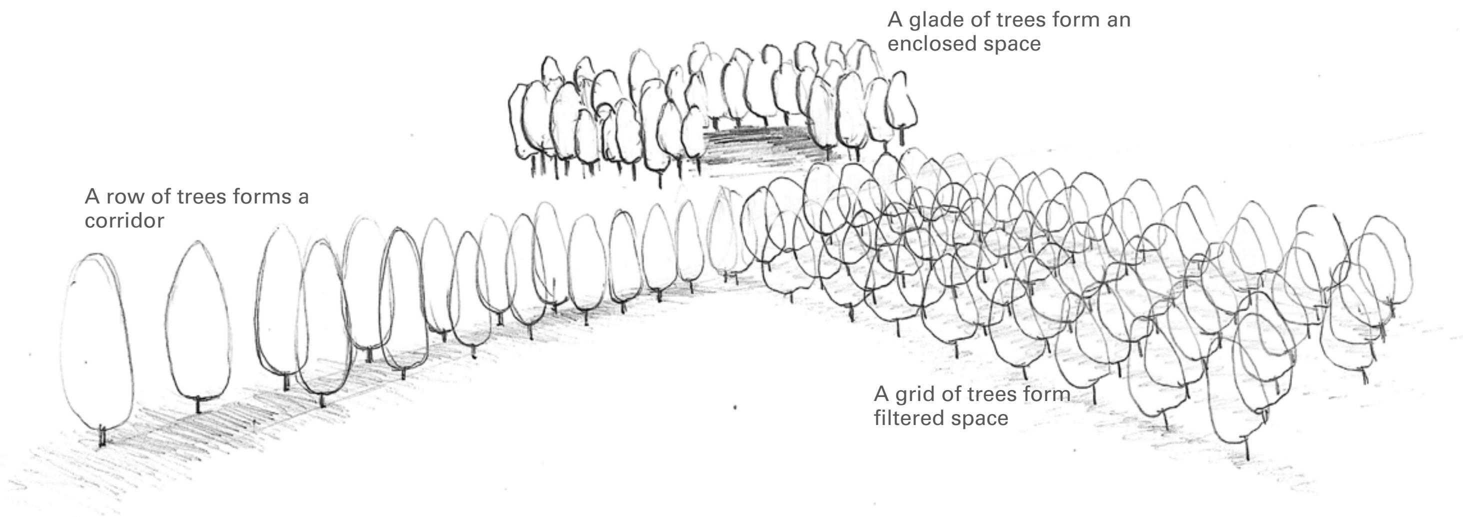


Figure 13: Planting patterns form variations of spatial enclosure

- **Planting colour** – Colour combinations are important considerations within a design aesthetic, for seasonal interest, for visual diversity, and to lead the eye to a particular part of the landscape. Colours can also combine seamlessly along gradients based on 'colour wheel' spectrums (refer Figure 15).

  Planting diversity - There are a range of local plant species that are common to stormwater devices. However it may be possible to include rare species, as long as there is an accessible and sustainable local seed or cutting source. Many native dioecious species (male and female on the same plant) require cross-fertilisation from a large population base for continued genetic diversity.

  Eco-sourcing from multiple parent individuals is an advocated approach to ensure genetic characteristics of a local population are not overwhelmed by the mass introduction of a remotely occurring relative. Rare plants should be introduced as appropriate for their context and only if the harvest of their seed does not compromise the existing population.

  Plant ecology – Ecological planting is the use of native species, planted in a manner that is representative of a like-environment for native plant communities. Native species have good survivorship, and may require less replacement and maintenance during the life of a stormwater management device.

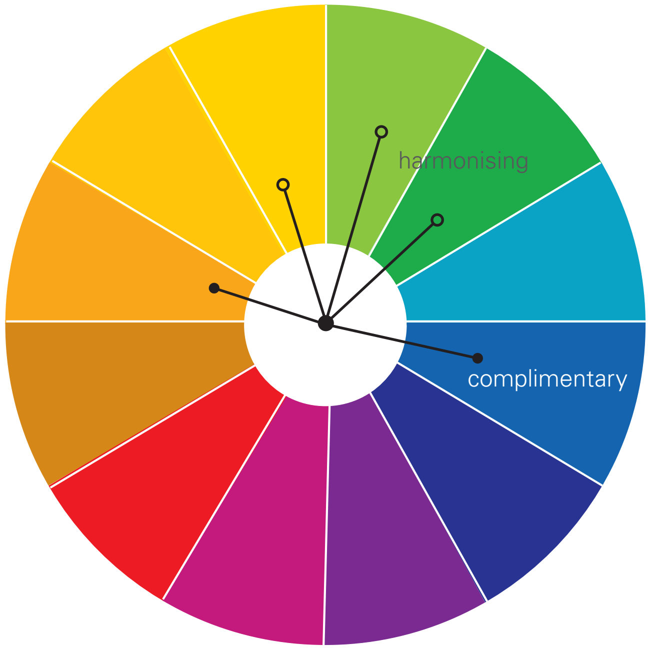


Figure 15: A planting 'colour wheel' indicating harmonising and complementary colour combinations

Figure 14: Diversity of forms, textures, tones, and colours of plants

- **Plant communities** – Species occur across environmental gradients responding to hydrology, exposure, and natural succession. Within plant communities there are also multiple tiers from ground, herbaceous, and shrub layers to mid-canopy and emergent vegetation. In order for some plant species to be present, plant associations and micro-climates may need to be established.
- **Wetland ecology** – As a stormwater treatment device, a wetland will occur in many varied hydrological and geological contexts. It may be appropriate to vary treatment wetland design according to the most appropriate wetland type for the local ecology, such as bog, fen, or marsh environments. In addition to emergent macrophytes, designs may also consider floating macrophytes and algae as appropriate for biodiversity and water quality treatment outcomes.
- **Abstract native planting** – Abstract planting is an artificial representation of natural plant communities. Stormwater devices are an opportunity to plant both natural systems (adjacent to receiving environments) and abstract systems (in line with deliberate planting schemes for a development). The best fit in many circumstances is to plant native species for biodiversity outcomes while responding to the landscape requirements of the urban framework. Examples of abstract planting include:

  a. Exotic plants may substitute a native where they are prevalent in the urban landscape, provide greater tolerance and productivity, or a desired landscape function. In this instance, avoid any plant in the Auckland Regional Pest Management Strategy (in all categories), any environmental weeds listed by the Department of Conservation, or any plant likely to spread and naturalise away from the site.

  b. Native plants can be massed in single-species bands. This may improve the efficiency of stormwater treatment function, reduce maintenance requirements, and may also interpret the processes at work within the treatment device through artificially reinforced patterns.

  c. Native communities can be abstracted in ways that differ from their natural composition such as clipped shrubs as hedges or native street trees.

  d. Natural processes may be compressed, by short transitions between ecosystems, unusual groupings of successional phases, and reduced plant diversity.

  e. Native plants outside of their typical habitat. A modified environment creates unique micro-climates e.g. riprap and green roofs may benefit from coastal or alpine species.

Abstractions may limit biodiversity and food webs through simplified ecological systems, and may result in a lack of environmental resilience. These would be of significant concern for a natural receiving environment. However abstract planting is a product of urban ecology, with relevant consideration for cultural norms, maintenance, climatic extremes, and modified systems. Planting in this realm is often a combination of the natural and modified, native and introduced, random and intentional.

Urban ecology can also be understood as a variation of what is understood to be 'nature', since both nature and culture are creative, evolving, and are reflections of their environments. One of the most dynamic elements that flows through both realms is water. This can be modified to express both natural and very formal/cultural constructs, accommodate both functional and aesthetic benefits, and meet the life giving requirements of people and humans.

Figure 16: Planting abstraction applied to stormwater management devices

(C) STRUCTURE

Structures are discussed in more detail for individual stormwater devices. Specific principles for structures relate to their relative inertness and their integration with plant and soil elements.

- Reduction in impervious surfaces – Where landscape constraints do not provide an opportunity to deal with stormwater passively through open space or within treatment devices, there may be opportunities to reduce the extent of impervious surfaces or provide for porous equivalents.
- Appropriate Materials – Inert materials should be selected to prevent heavy metals, fine persistent particles, or chemical residue from entering stormwater.
- Green structures/ Green Engineering – Vegetated green roofs and floating island systems are examples of structures applied to constrained environments, that perform a stormwater management function while contributing to landscape and ecology values. At all design points, structures should be assessed for their potential to provide for multiple functions in this way.

Figure 17: Structures responding to stormwater management . Images left source www.greenroofs.com

Figure 18: Structures that define the edge of stormwater systems while contributing to landscape amenity and public access. Above image courtesy of Syrinx Environmental PL (AILA LA Papers: http://www.aila.org.au/lapapers/papers/syrnix-perth/default.htm)

Figure 19: Biotechnical approaches to channel and bank stabilisation, provide the means to support plants based systems

2.0 LANDSCAPE SPECIFICATIONS

2.1 SOILS

Healthy soils provide the following services or functions to support stormwater management, landscape and ecology:

- Minimise runoff by attenuating water in organic matter and infiltrating water into freely draining soil.
- Oxygen present in aerated and well drained soils provides for plant root growth and stimulates micro-biologies. This is important for nutrient cycling and plant resilience.
- Store, supply and cycle nutrients through complex microbial associations in the soil, making nutrients available to plants and minimizing leaching of nutrients into ground and surface water. Continued nutrient cycling requires the breakdown of larger organic matter through the biological activity of worms, insects and fungi.
- Structural support for larger plants, while allowing root penetration through friable soils.

AUCKLAND SOILS

Large areas of the Auckland region are underlain by Waitemata geology on which ultic soils are dominant. These soils typically have low subsoil permeability leading to a bypass of stormwater flows. They are highly vulnerable to compaction, variation in permeability, and have relatively shallow rooting depths. Ultic soils are typically yellow-brown clay subsoils and may have grey or red mottling, and coarse blocky or prismatic structures.

Allophanic Soils have high permeability and moisture storage potential and are found in small pockets (generally <1 ha) amongst ultic soils. Allophanic Soils generally occur on gently sloping (<10°) or flat broad ridges and terraces. Allophanic Soils are identified by reddish yellow brown, or yellowish red silty subsoils with a friable, greasy or soapy feel.

Granular soils have similar properties to allophanic soils. They occur on red- weathered sandstone and can be identified by closely-spaced auger surveys into upper subsoils (0.5m depths at 10m spacing). Granular Soils are identified by chocolate brown, clayey subsoils with finer blocky structures..

MANAGING SOILS IN-SITU

Many soils of the Waitemata geology are highly vulnerable to degradation, difficult to rehabilitate over large areas, and take many years to recover naturally. The most appropriate means to preserve soil structure on a site is to limit disturbance through erosion control and restrictions to the limit of work.

Where practicable, granular and allophanic soils should remain un-trafficked for their benefits to stormwater management and for their potential to support deep-rooted trees. A less favorable option is to stockpile permeable soils for re-spreading. This generally leads to compaction and mixing with less-permeable soils. Auckland soils vary unpredictably over tens of metres, and mixing can reduce soil qualities to that of the poorest on the site.

A pre-disturbance survey should identify soil resources and potential soil liabilities. This may reveal soils suitable for raingardens (rapidly-draining soils) or wetlands (organic soils or peats). Scoria or rock may be utilised for landscape structures, drainage, or lizard habitat.

Figure 20: A granular soil horizon

Figure 21: An ultic soil horizon

Conventional cut to fill earthworks typically form truncated anthropic soils (NZ classification, Hewitt 1998), with sharp transitions from topsoil to subsoil. This is exacerbated by multiple earth-moving operations, handling soils in wet conditions, and cuts greater than 0.5 to 1m depths. Truncated anthropic soils generally result in perched water tables, limited root development and reduction in water storage.

Where areas of soil and vegetation are subject to earthworks the key practices to enhance soil function are:

- Sites with hydrologic group A and sandy group B soils, from the unified soil classification system (USCS), should have earthworks restricted to roads and building footprints where practicable, particularly in areas designated for stormwater disposal ('stormwater reserves') and parks.
- Areas of vulnerable soils which are to be replanted post development should not be trafficked unless conditions are dry and vehicles are light.
- Minimise compaction by maintaining vegetation cover. In the short term mulches, especially organic mulches, can protect soils from foot traffic. Mulch also retains soil moisture to prevent cracking.
- The application of mulch can reduce water entering subsoils, and certain mulches (bark and woodchip) can strip nitrogen and introduce weed seeds. Therefore the source and depth of mulch should be assessed prior to spreading.
- Avoid mowing when soils are saturated.
- Ensure equipment is cleaned before getting to a site to reduce the risk of spreading weed species and soil pathogens.
- Prevent and control erosion, especially of topsoil, by minimizing the extent and duration of bare soils.
- Retain wetlands and wet storage areas, but prevent ponding in earthworked areas.
- Divert overland flows from bare soils.
- Evaluate compaction and grading requirements i.e. paved areas do not require the same level of compaction as building platforms. Use the lightest equipment necessary to get the job done and achieve final grades with as few passes as possible.
- Restrict soil stripping and replacement, especially the upper 0.3 m of subsoil and topsoil, to dry periods when soils have the highest bearing strength and the most resilience.
- In extremely sensitive areas, on highly permeable soils, build houses on piles, rather than slab-on-grade, to avoid contouring and consequent soil degradation.
- Protect root systems of existing large trees by suspending or supporting pavement/road over soil, installing grates around tree trunks, or placing gravel or organic mulch over soil surfaces to reduce compaction pressures.

Figure 22: Ultic soils following compaction

SOIL STRIPPING

Topsoil is a dark-brown layer usually 100 to 400 mm deep, characterised by the presence of organic matter. Other valuable soil structures include peat deposits and freely-draining subsoils (usually bright red-brown in colour with very few mottles).

Soil stripping inevitably damages soil fauna, particularly earthworms and large invertebrates that break down and recycle leaf mulch and release nutrients for plant growth. Soil stripping and stockpiling also tends to destroy soil structure and lower soil carbon content. Where necessary, the quality of stripped topsoils can be optimised in the following ways:

- Ensure machine operators can differentiate between topsoil and subsoil by colour.
- Excavate only during daylight hours and when soil moisture conditions ensure wheel ruts are <50 mm depth. Do not excavate during rain.
- Use backacters or face-shovels to remove topsoil, not earth-scrapers, particularly for soils vulnerable to degradation (imperfectly to poorly-drained soils on Waitemata Formation) or where soils are highly variable (e.g. brownfields). Maintain soil structure (large clods) and avoid re-handling topsoil (do not bulldoze into piles that are then removed to stockpiles).
- Remove the entire topsoil depth at one time and restrict traffic to subsoil layers to preserve soil structure and minimise compaction. Where access by machinery is essential, utilise low ground-bearing vehicles to reduce compaction of subsoils especially in areas intended for replanting. Do not allow access to wetter soils.
- If woody vegetation is removed, consider mulching or chipping vegetation and adding to topsoil. The chips will help reduce compaction, especially in longer term stockpiles. Be aware that the mulch will also strip nitrogen from the soil as it decomposes, so a slow release fertiliser or nitrogen-containing compost will need to be added to the soil when re-spread to assist plant growth.
- Large branches, tree stumps and rocks that could damage cultivation equipment should be separately stockpiled, preferably after topsoil has been stripped to reduce topsoil compaction.
- Kill herbaceous vegetation 3 to 6 weeks before stripping and identify areas of potentially high-maintenance weeds, e.g., kikuyu, to separate and manage appropriately.

SOIL STOCKPILE MANAGEMENT

Stockpiling should be avoided where possible to reduce the impacts to topsoils, to avoid double-handling, and to minimise the area of bare land. Where necessary, the following practices will help maintain the quality of soils in stockpiles:

- Designate areas for stockpiling.
- Prepare stockpile areas by ensuring surface water is intercepted and diverted around the stockpile. Construct sediment control features to capture and treat runoff from stockpiles if required. Ensure the base is relatively even and well drained to minimise anaerobic conditions developing at the base of the stockpile. Under-drainage may be beneficial.
- Construct stockpiles by dump trucks and avoiding over-compaction; reshape using backacters not bulldozers. Topsoil stockpiles should not be trafficked by any machinery.
- Topsoil stockpiles should be no higher than 1.5 to 2.5m.
- Straw mulch should be applied for stockpiles remaining for more than 3 to 6 months or over winter.
- Spray off vegetation on stockpiles before use.

Where anaerobic soils have developed at the base of stockpiles, there will typically be elevated iron and reduced pH (as low as 4 to 5). These soils should be ameliorated (refer soil enhancement section following) before placement in stormwater management devices to avoid leaching of contaminants (ammonium, metals) or unsightly materials (iron flocc) into waterways.

TOPSOIL SPREADING

Higher value topsoils should be targeted for areas of permanent vegetation, spread to depths of at least 300mm to new planting beds, and 100mm to grass areas. The following strategies should be adopted for placement of topsoils:

- Use low ground-pressure machinery or selected lightweight tracked or balloon tyred equipment operating along approved traffic routes.
- Remove all building debris and contaminated material (debris, road base, oil spills etc).
- Ameliorate subgrades prior to placement of topsoil to achieve loose, friable conditions to 500 mm below final topsoil grade, with a minimum 300 mm for turf areas and 1000 mm for trees (see following section).
- Ensure a 100 mm interface with subsoils, and mulch to prevent crusts forming.
- Spread soils when they are slightly moist but not wet to yield the greatest structural stability.
- Cover ameliorated areas with a full depth of topsoil as soon as possible and when moisture conditions are favourable. Where soils are well-drained, topsoil can be applied in two layers with an initial 50 to 75 mm depth of topsoil roto-vated into the subsoil to encourage even drainage and rooting into the subsoil. If soils are imperfectly drained or fine-textured, the risk of re-compaction can be reduced by applying a full-depth of topsoil in a single pass.
- Check the final contoured surface for ruts, rilling, or dishes where surface water may flow and concentrate.
- Hydroseed, mulch, or seed the re-spread topsoil immediately to protect surface from sealing or eroding.

SOIL ENHANCEMENT

AMENDMENTS

Most earth-worked soils will be physically or chemically degraded to some extent, especially if they have been stockpiled. An effective method of reviving degraded soils is to incorporate organic materials such as compost. Compost should be mixed into the upper 200 mm of all areas that are disturbed or compacted in urban areas to achieve topsoil organic contents between 5 and 10% (Anon, 2009). This level promotes plant growth, water uptake and water storage (Hanks and Lewandowski 2009).

This approach is supported in New Zealand, particularly for degraded soils and for poorly-structured fine-textured soils common to North and West Auckland. Organic contents in excess of 10% may result in uneven subsidence. Composts should be well-aerated and relatively stable and conform to the NZ composting standards (NZ Standard NZS/AS 4454,).

Another additive to ameliorate soils is Gypsum (calcium sulphate di-hydrate), an abundant natural mineral found in Australia used as a soil conditioner and fertiliser, improving soil texture, drainage, and aeration. Gypsum is appropriate for the remediation of compacted soils, exposed subsoils, or soils affected by salinity (eg. estuarine berms, dairy effluent disposal areas). Gypsum has an advantage over certain other minerals, being pH neutral. Mychorrhizae fungi can also be incorporated (through inoculation by spray) into topsoil horizons to accelerate soil biodiversity and productivity.

The application of organic mulch to a depth of 50 to 75 mm depth will suppress weeds, reduce frost heave, and break down over time to enhance organic content in topsoil. Mulches hold water entering the soil, so need to be spread on moist soil before dry weather. Care should be taken before applying mulch to poorly-drained areas, as mulch acts to reduce water loss and therefore exacerbate development of anerobic conditions.

CULTIVATION

Upper horizons of Allophanic and Granular Soils can be ameliorated using a combination of mechanical cultivation and amendments, as they fracture into a fine tilth over a wide range of moisture contents. These topsoils can be deepened to 300 mm if soils are aerated and compaction is limited.

In contrast, most Ultic Soils cannot be effectively cultivated, as they fracture over a narrow moisture range. Ultic Soils are generally unsuited to amelioration using sand amendments, but compost amendments may be effective.

Cultivation at the transition between subsoils and topsoils can provide for increased water percolation and root movement into subsoils. Hydrologic group A and coarser-textured group C soils (USCS) can be incorporated into subsoils to enhance their drainage properties. Cultivation of subsoils is most effective on a two-directional grid.

Avoid roto-cultivators for subsoil cultivation as they tend to create a smooth base that becomes a root barrier. Slopes greater than 10 to 15 degrees may require specific cultivation methods, and care must be taken around trees, utility lines, slopes, and retaining structures. Recently air-blasters have been used to remove soils around the roots of trees in Auckland's Victoria Park with minimal damage.

Hydro jetting, deep-water jetting, and air injection have been used to fracture compacted subsoils in urban areas. However, the availability and suitability of this equipment in Auckland has not been assessed.

OTHER METHODS OF SOIL ENHANCEMENTS

Grass heights over 100 mm or dense tree planting increase soil macroporosity and permeability through root activity. Trees also add organic matter and enhance the diversity of biological interactions in the soil. Plants evapo-transpire to create increased water absorption capacity in the soil. Evapo-transpiration increases with solar aspect through grid planting and transitional planting heights.

'Structural soil' under footpaths to road edges forms large continuous volumes for tree roots and water storage. Structural soils are based on sand/compost mixes and have high bearing strength and permeability. They have not been widely applied in New Zealand, but are possible in line with standard paving mixes and specifications from the United States (Bassuk et al. 2005). Synthetic structural cells provide a similar function to structural soils. Radial trenches from trees also provide a means to increase soil in constrained areas.

SOILS FOR STORMWATER MANAGEMENT DEVICES

In some cases local soils can be amended to provide substrates that are suitable for stormwater management devices. The most common amendments are sand and organic material such as compost, peat or wood chips (used to enhance nitrogen removal). Amendments specific to stormwater treatment devices may include zeolite, perlite and potentially materials such as steel slag, designed to increase removal efficiency of dissolved metals and phosphorus.

2.2 PLANTING

PLANT MATERIALS

It is essential to ensure plants that are sourced from nurseries are free of environmental weeds such as African clubmoss and pests such as Argentine ants. The introduction of pest plants from nursery stock has seen large stormwater devices dominated by weed species in only a few seasons.

Ideal plant specimens will have well developed root systems and be free of disfigurements, pests, and disease. In areas exposed to the coast or high winds, plant stock should be 'hardened off' to cope with climatic conditions, which usually requires one to three months placed in conditions similar to the intended site (Malcolm & Lewis 2008).

Plant sizes greater than PB3 (3 litre plant bag) are more likely to survive pukeko browse. However, smaller plant sizes, such as root trainers, are more economic, can be wedged tightly into soils in flow paths, and can fit into biotechnical materials such as coir fascines without affecting their structural integrity.

Nursery-propagated plants should be used (never collect plants from the wild), and plants should be eco-sourced from local seed or cuttings where appropriate and only by certified practitioners. Ecosourcing conserves natural, genetic and phenotypic diversity in local native plant populations. These plants are also more likely to adapt to local growing conditions (Boffa Miskell 2007; WCC 2005).

SET OUT

Planting should follow an approved planting scheme, indicating composition and spacing of plants. Plants should be placed in accordance with their environmental tolerances, directed by a knowledgeable supervisor. Plants should be staggered in odd numbered groups (for plant numbers less than 10), unless otherwise intended by the planting design.

Spacing will vary between small rushlike and fern species at four plants per square metre and tall/spreading species at 1200 mm spacings. Trees should be placed individually. All plants should be laid out in their bags prior to planting to ensure appropriate lay out.

FERTILISERS

If initial soil nutrition, pH and depth are adequate, soils supporting perennial, un-mown vegetation will rarely need fertilising. Pale green and yellowing plant foliage is often due to inadequate aeration, not inadequate nitrogen, so it may pay to check the soil physical condition before the application of fertiliser. However, where fertiliser is determined appropriate (e.g. nutrient-deficient soils), slow-release tablet fertilisers can be applied into the base of the planting hole for roots to absorb the nutrients (Boffa Miskell 2007).

Fertilisers should be avoided in planted areas immediately adjacent to watercourses. Bioretention and filtering devices should not be fertilized, as they receive nutrients from off-site during stormwater flows.

TIMING

Planting times vary according to environmental conditions.

- In the Auckland region, the planting season is from May to September. This will generally achieve optimal plant establishment and survival, with reduced maintenance.
- Open water and wetland planting should occur in late spring to early autumn (September to October and March to May) when water levels are low and the water is warm. Hardy frost-tolerant species can be planted in autumn, and frost-sensitive species in spring.
- Careful timing of planting at the right season will reduce the need for watering. However, in dry spells young plants may require more watering to assist with their establishment.
- Plants that need shelter or shade can be planted one or two years later, once adjacent cover has developed.

MULCH

Mulch is a surface layer of stones, gravel or organic material that provides the following functions in stormwater devices:

- Weed suppression until a dense vegetation cover is achieved. Kikuyu and other rhizomous plants may be advantaged by mulches and should be controlled prior to mulching.
- Short-term surface stablisation through prevention of a surface crusting, rilling, or entraining sediments.
- Long term erosion resistance around inflow and overflow structures, often as riprap stacked to freeboard levels.
- Short and medium term contaminant removal (including nitrogen).
- Plant nutrition (for organic mulches).
- Increasing moisture supply and retention during plant establishment, especially if irrigation is difficult/costly, establishment is in late spring and the substrate is coarse (very sandy) with low organic content.
- Cushioning the impact of foot traffic.
- Creates short-term interest and amenity, and reinforces planting patterns.

Grass clippings or animal waste should not be used as mulch in stormwater management devices as they may act as a source of contaminants, such as nitrogen and fecal coliforms. Mulch should be laid at depths over 75mm, except around the base of shrubs and trees to avoid rot.

An erosion control fabric is recommended for areas subject to water flow or on steep banks. A matting that combines weed suppression, mulching, and erosion control may be applicable in this situation. Biodegradable matting should be favoured to contribute to soil biology.

Once plants are established mulching will only be necessary at the edges of stormwater devices and around inflows where sediment accumulates.

Organic mulches should provide for the following:

- Coarse graded, long fibred mulch that self-binds. This avoids mulches that float in stormwater devices (such as bark nuggets).
- Mulch should be well aged and free of weed seeds, soils, roots, and plant fragments.
- Mulch made from composted greenwaste will usually provide valuable plant nutrients, while avoiding nitrogen stress.
- Coarse and bark mulches generally last longer than fine mulches.
- Most organic mulches will enhance removal of contaminants and therefore extend the treatment life of a raingarden.

Chemical mulches can be applied hydraulically to adhere to the soil, and potentially assist with flocculation. These are most relevant for larger devices.

Establishing a dense, low cover of plants can be an effective alternative to mulch. This method is especially useful on sloping banks where mulch will not hold or where loose mulch may contaminate a watercourse (Boffa Miskell 2007).

2.3 WEED AND PEST CONTROL

WEED AND ANIMAL PEST CONTROL

Weed species can permanently alter the structure and ecological processes of native plant communities. Introduced mammals predate directly on native fauna (birds, lizards and insects), and compete with them for resources through browsing.

Weed and animal pest control around stormwater devices should be undertaken to protect new plantings as well as local biodiversity. During the establishment phase, new planting is particularly vulnerable to competition from weeds, as well as damage by pukeko, waterfowl, and rabbits.

Complex food web interactions occur within all ecosystems and consequently careful planning is required for any control operation. The removal of a single pest can result in adverse affects on native wildlife. For instance, the possibility of prey switching (from introduced to native species) can occur if rats are removed from a system in which cats remain. Alternatively, the removal of cats from a system in which rabbits remain may result in an increased browsing pressure on native plant species. As such, a coordinated multi-species approach to any control operation is recommended.

For plant communities, a combination of direct weed control, suppression by native planting, and allowing for native succession provides for long term weed management, with minimal impact to native vegetation, and reduced maintenance costs.

INTEGRATED PEST MANAGEMENT

Integrated pest management (IPM) maintains pest population at levels below those causing ecological damage. Thus, IPM is not a single pest control method but, rather, a series of pest management evaluations, decisions and controls. The four steps to IPM include:

- Set Action Thresholds - Before taking any pest control action, IPM first sets an action threshold, a point at which pest populations or environmental conditions indicate that pest control action must be taken. Sighting a single pest does not always mean control is needed. The level at which pests will become an ecological threat is critical to guide future pest control decisions.
- Monitor and Identify Pests - The most cost-effective and efficient way to reduce unwanted plants and animals is to stop them from becoming established. Most pest invasions start with the arrival of only a few individuals to a site. Early detection and control is therefore crucial to keep problems to a minimum.
- Prevention - As a first line of pest control, IPM programs work to manage the habitat / environment to prevent pests from becoming a threat. For example, dense planting to reduce open disturbed sites that are prone to weed invasion.
- Control - Once monitoring, identification, and action thresholds indicate that pest control is required, and preventive methods are no longer effective or available, IPM programs evaluate the proper control method both for effectiveness and risk.

  Low risk pest controls are chosen first, including mechanical control, such as trapping or hand weeding. If further monitoring, identifications and action thresholds indicate that lower risk controls are not working, then additional pest control methods would be employed, such as targeted spraying of selective pesticides. Broadcast spraying of non-selective herbicides will leave bare ground that is prone to weed invasion.

  It is important to keep in mind that insects and soil micro-organisms perform a vital role in maintaining soil structure, and the use of pesticides should be avoided where practicable.

SURVEY AND MONITORING

Prior to any construction works, it is advisable to carry out a thorough survey of adjacent natural areas, especially upstream of ponds and wetlands, to identify unwanted fish and weeds in the vicinity. This will enable the implementation of a control plan based on the risk of invasion. If aquatic weeds are present in the contributing catchment, it is advisable to eradicate them where practicable to prevent their spread to stormwater devices.

Once construction begins conduct regular checks for unwanted plants and animals. Check for weeds and pests monthly during construction (and during the first 4-6 months of plant establishment), then every 3 months for the first 2 years. Following this period, checks 2-3 times a year are recommended. In addition to regular checks, check ponds and wetlands after major flooding events as these can wash down unwanted plants and fish from upstream water bodies.

The following sections outline the methods incorporated in an IPM programme for weeds, insects, and animal pests (birds and mammals).

WEEDS

Weed control in the establishment phase is essential for the success of wetland and embankment plantings. Weeds must be controlled to remove competition with desirable plants for light, nutrients and moisture. Smothering by tall grass is the most common cause of plant failure. Once plants have grown tall enough, they will begin to shade out grasses and aquatic weeds.

Maintenance of proper water levels combined with occasional deeper flooding can control many non-aquatic weed species which may colonise sediments of stormwater devices. Ponds or wetlands that receive plenty of sunlight and nutrient rich run-off can become choked with algae and water plants. A good inflow of water is needed to continually flush the pond or wetland and extra depth will help keep it cool. Overhanging trees and planting can provide shade to open water such as wetland forebays.

Creeping and sprawling weeds such as mercer grass (*Paspalum distichum*) and kikuyu grass (*Pennisetum clandestinum*) can form floating mats across wetlands and ponds. Control of embankment weeds is generally better achieved by dense plantings around the margins of stormwater treatment devices, using hardy species such as flax. This also has the advantage of stabilising embankments and providing cover for wildlife (Tanner et al. 2006). A densely planted margin of ten metres from a wetland edge should inhibit the spread of herbaceous weed species into these systems.

It is always best to keep weeds at low levels, when they require minimal input for control. Options for weed control include hand-weeding, grubbing, slashing, ring barking, and spraying (herbicide). Herbicides should be used sparingly and only when necessary in stormwater devices. Chemicals are transported rapidly through water, making wet areas more sensitive to pollution and herbicides.

Mulch is discussed in previous sections. Adopting high planting density rates will help to combat weed invasion and reduce maintenance requirements for weed removal (WSUD 2006).

In order to prevent the spread of weeds, contractor responsibilities should include:

- Ensure construction equipment is cleaned before transport to site.
- Ensure topsoil, mulch, and plants transported to site are weed free.
- Removal of all weed material from the landscape areas to a designated collection facility off-site.

MOSQUITOES

Mosquito eradication is difficult and short lived. Controls for mosquitoes generally manage population numbers to a tolerable level (Russell & Kuginis 1998). Mosquito management can be achieved by a composite approach as part of integrated controls. This involves the use of complementary methodologies designed to reduce the mosquito habitat or make it unsuitable, encourage natural regulation by predators, and limit the use of environmentally damaging control agents such as pesticides (Russell & Kuginis 1998).

To avoid mosquito problems design conditions that are unattractive to mosquitoes or are not conducive to larval development:

Open, high nutrient, stagnant water creates excellent mosquito breeding habitat and larval development and should be avoided (Martin et al. 2008):

- Maintaining water movement through stormwater devices will prevent the formation of pools of stagnant water and in turn reduce mosquito populations.
- Riffle zones provide turbulence which is detrimental to larvae and serves to raise oxygen levels and improve water quality.
- Shallow water depths (150mm minimum) allow predator access.
- Establishment of vegetation within and surrounding devices will create shading, thereby cooling the water temperature and reducing mosquito habitat.

Never introduce gambusia (*Gambusia affinis*) as a biological control agent to any waterbody; their ability to control mosquitoes has been exaggerated and they attack native fish and prey on their eggs. Whitebait and mudfish species are especially vulnerable as they inhabit similar habitats to gambusia. Native fish such as whitebait, bullies, eels and aquatic invertebrates all feed on mosquito larvae. Habitat should be created for these species where appropriate so that these natural predators can help to control mosquito populations.

BIRDS

Pukeko and some waterfowl can cause serious problems in new plantings. They pull small sized plants out of the ground, feeding on roots or the insects associated with them. Pukeko tend not to land in areas of standing water, therefore maintaining water depths of 100 mm can provide an impediment to their entry (Tanner et al. 2006).

Options for pukeko control and waterfowl are limited in urban areas but can include the use of electric trip wires spaced 200–300mm apart and 100mm off the ground around the margins of stormwater management devices and along any internal embankments. Pinning aquatic plants and grasses with 300mm "U" shaped wire pins can reduce the damage done to new plantings by pukeko, or alternatively use larger potted plants (PB3). Other options include installing bird proof netting or additional stakes and ties to the plants. Pukeko will generally stop removing plants about six weeks after planting (Martin et al. 2008).

Signage should be placed around constructed wetlands or ponds discouraging the public from feeding waterfowl. Limiting fly-ways, loafing areas, and increasing the ratio of planting to open water will also reduce the numbers of waterfowl.

MAMMALS

Animal pests pose significant risks to native birds and plants. Possums, hedgehogs, stoats, weasels, ferrets, cats and rats all take birds' eggs, and most will also eat chicks and adult birds; rabbits, hares and possums eat wetland plants; and dogs may harass wetland birds. On-going mammal pest control and management will enhance native biodiversity (including birds, lizards and insects) for some stormwater devices and protect juvenile planting.

A number of control techniques are available, including trapping and poisoning, with the most appropriate method depending on the pest species that are present and the use of the space by the public. As discussed previously, the selected methodology should be applicable to multiple species, with specific regard for interactions between target species.

LINKS

ARC GUIDES

ARC Regional Pest Management Strategy (RPMS) - The RPMS defines ARC's priorities and goals regarding control of animal and plant pests across the Auckland region.

http://www.arc.govt.nz/plans/regional-strategies/regional-pest-management-strategy-2007-2012.cfm

ARC Integrated Pest Management Fact Sheet – http://www.arc.govt.nz/albany/fms/main/Documents/Environment/Plants%20and%20animals/Intergrated%20Pest%20Management.pdf

ARC Plant Search
http://www.arc.govt.nz/plantsearch

ARC Pest Plant Control Techniques
http://www.arc.govt.nz/environment/biosecurity/pest-plants/pest-plant-control-techniques.cfm

ARC Planning Pest Control
http://www.arc.govt.nz/environment/biosecurity/pest-plants/planning-your-pest-control.cfm

ARC Herbicide and Additives
http://www.arc.govt.nz/environment/biosecurity/pest-plants/herbicides.cfm

ARC Guidelines for Intensive Pest Animal Control
http://www.arc.govt.nz/environment/biosecurity/pest-animals/guidelines-for-intensive-pest-animal-control.cfm

ARC Planning Your Pest Control
http://www.arc.govt.nz/environment/biosecurity/pest-animals/planning-your-pest-animal-control.cfm

OTHER SOURCES

Weedbusters – A weeds awareness and education programme that aims to protect New Zealand's environment from the increasing weed problem. Information regarding identification, threat, biology and control methods.

http://www.weedbusters.org.nz/weed_info/advanced.asp

New Zealand Plant Conservation Network - Search for 1500 weed fact sheets mainly derived from the Department of Conservation's BIOWEB weeds database. Includes information regarding history of introduction, habitat, species biology and differentiating similar species.

http://www.nzpcn.org.nz/exotic_plant_life_and_weeds/advanced_search.asp

Global Invasive Species Database - aims to increase awareness about invasive alien species and to facilitate effective prevention and management activities. http://www.issg.org/database/welcome/

Environment Bay of Plenty fact sheets - Methods for identifying and controlling pest plants and animals occurring in the Bay of Plenty.

http://www.envbop.govt.nz/weeds/weed-index.asp

Landcare - Information regarding identification, biology regional obligations, advisory organisations for animal and plant pests. http://www.landcare.org.nz/biodiversity/biodb_index.htm

National Pest Plant Accord - This manual contains photographs and descriptions of plants that are considered pests throughout New Zealand.

http://www.biosecurity.govt.nz/files/pests-diseases/nppa/nppa-pest-plant-accord-manual.pdf

Christchurch City Council weed guide – Identification and control information. http://www.ccc.govt.nz/parks/TheEnvironment/weedguide_names.asp

Journal of the Royal Society of New Zealand – Volume 31 (1) is a special issue on "Advances in New Zealand mammalogy 1990 2000". For each species, information regarding habitat, food, social organisation and behaviour, reproduction and development, population dynamics, significance to New Zealand, and options for control are discussed.

ERMA

Hazardous substances http://www.ermanz.govt.nz/hs/index.html

Substance register http://www.ermanz.govt.nz/search/registers.html

3.0 GREEN ROOFS

Rooftops represent approximately 40-50% of impermeable surfaces in urban areas. Therefore, green roofs have the potential to play a major role in stormwater management (Dunnett & Clayden 2007). Compared to other local stormwater management solutions, green roofs have the advantage of requiring no additional space to be designated (Villarreal 2005).

Green roofs are vegetated layers that sit on top of conventional roof surfaces and can be categorized as 'intensive' or 'extensive' systems. The two systems differ in media depth, plant material, maintenance requirements, and provide different uses for rooftop areas (refer to the adjacent table).

Intensive green roofs (also known as high-profile or roof gardens) are composed of relatively deep substrates that can support a wide range of plant types (trees, shrubs, grasses) and structures (including water features). These roofs are generally heavy and require structural supports. Intensive green roofs are often accessible spaces, providing elevated gardens or parks (refer figure 23 and Table 1).

Extensive green roofs (also known as low-profile or eco-roofs) are composed of lightweight layers of free-draining material that supports low-growing drought-resistant vegetation. Extensive green roofs can be designed into new buildings or 'retro-fitted' onto existing buildings. They are commonly designed for maximum thermal and hydrological (reduced stormwater runoff) performance and minimum weight load while retaining the aesthetic and environmental benefits of plants. This type of roof is not normally designed to be accessible, except for maintenance, and may be flat or sloping (Grant et al. 2003). However, they may be visually accessible, seen from adjacent buildings, or as foreground to distant views.

	INTENSIVE GREENROOF	EXTENSIVE GREENROOF
ADVANTAGES	• Greater diversity of plant species and sizes • Good insulation properties • Accessible recreation area • Retains greater stormwater runoff	• Lightweight construction • Suitable for any size roof • Suitable for angled roofs • Low maintenance • Little technical expertise required • Relatively inexpensive • Require less planting media • No need for irrigation and drainage systems
DISADVANTAGES	• Greater weight loading on the roof (up to 1m of soil) • Irrigation requirements • Higher cost • Complex systems	• Limited choice of plants • No recreation access • May be unattractive in drought periods when plants are stressed

Table 1: Table illustrating properties for extensive vs intensive green roof types

Figure 23: An example of an extensive green roof (left) and an intensive green roof (right)

3.1 LANDSCAPE

Green roofs contribute to green networks through urban areas, and also provide ancillary benefits of stormwater management, lower ambient temperatures, interception of dust, and enhancement of air quality. Intensive green roofs additionally provide opportunities for passive and active recreation, as urban sanctuaries and private gardens. They even provide opportunities for horticulture.

Other landscape benefits provided by green roofs include (refer figure 25):

- A variety of texture, tones, and colour in monotonous roofscapes.
- Screening infrastructure and equipment on rooftops.
- Pleasant views to the rooftop from distant areas.
- Enhanced natural character values.
- Natural elements integrated with architecture (smells, colour, texture, and movement), with resulting psychological benefits.

Green roof landscapes are often appreciated by a wider audience, looking onto the rooftop from surrounding buildings. Landscape design is therefore a function of plant form and planting patterns for near views (where individual plants can be appreciated) and textures, tones, and colours from distant views where broader patterns are read.

Figure 24: Abstract patterns on green roofs lead the eye and forming virtual spaces

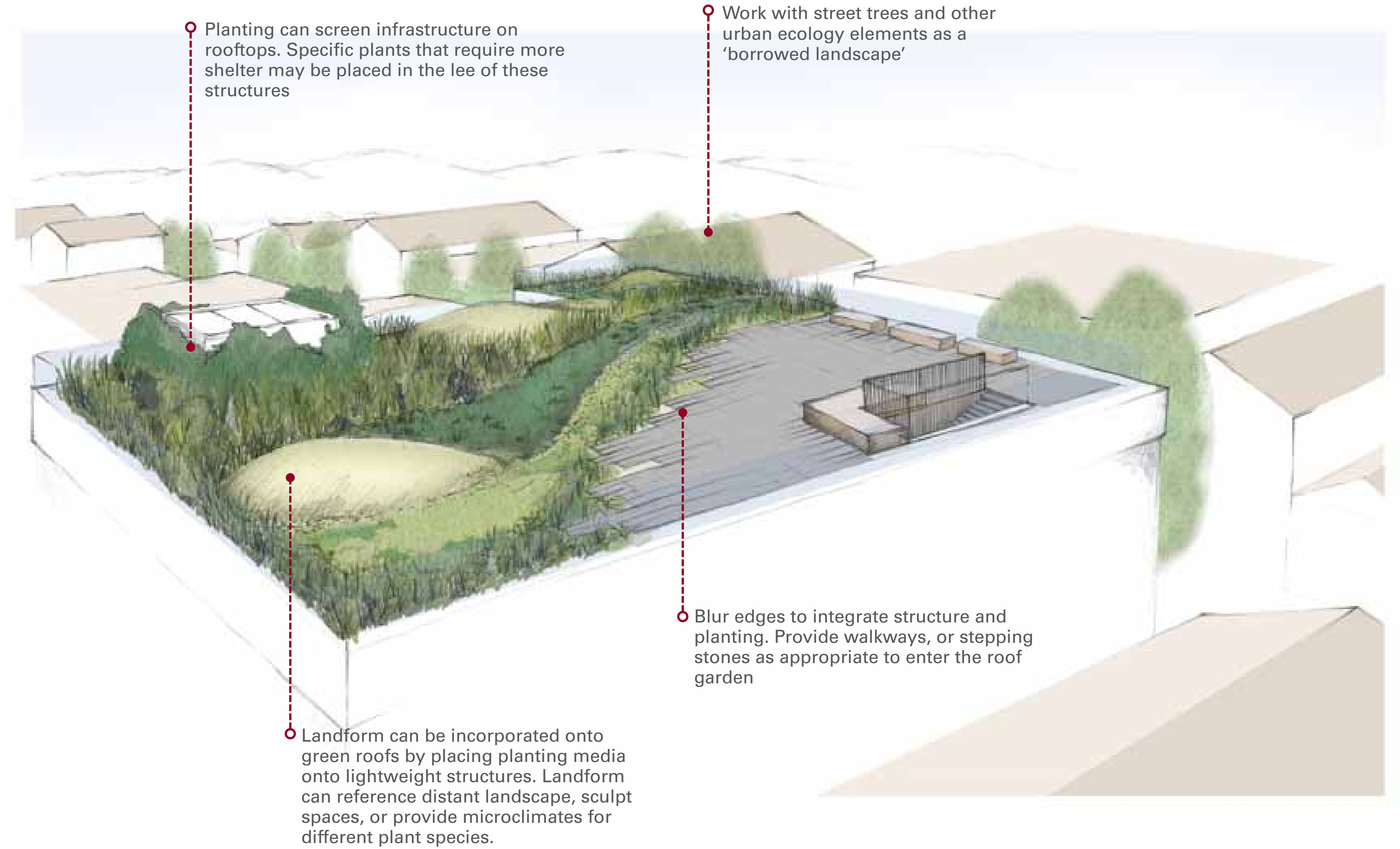


Figure 25: Landscape elements to consider for green roof design

3.2 ECOLOGY

Green roofs can provide suitable habitat for animal and plant species that are able to adapt and develop survival strategies for extreme local conditions or are mobile enough to move between habitats (Brenneisen 2006).

Existing studies have found that a wide range of plant, bird and invertebrate species do occur on green roofs (Grant et al. 2003). Designing green roofs so that they have varying substrate depths and drainage regimes creates a mosaic of microhabitats on and below the soil surface and can facilitate colonisation by a more diverse flora and fauna (Brenneisen 2006).

Dense development in urban areas interrupts green (habitat) corridors or links. Within the inner urban core of some cities, green roofs may be the only green space available, providing links or stepping stones in an intermittent network of habitats, thereby facilitating wildlife dispersal (Grant et al. 2003; Dunnett & Kingsbury 2008).

Although the use of green roofs has become relatively commonplace, those designed specifically for biodiversity are still uncommon. In practice, most habitat creation on roofs has been limited to low growing, open or sparsely vegetated areas where vegetation succession is slow or arrested because of thin soils. However, if suitable niches are available or provided, then plants and animals will colonise and establish communities (Kadas 2006).

It is important to note that many of the plant species used in green roofs overseas such as succulents and sedums are environmental weeds or have become naturalised in New Zealand. Green roofs near vulnerable natural environments such as coastal or inland cliffs, or sub alpine areas, should use native species that are not cultivars.

In a study assessing the potential of green roofs for bird conservation in the UK, Burgess (2004) found that 70% of bird activity involved vegetation. Birds spent most of their time feeding and collecting nest material. A design feature found to be advantageous for birds is the incorporation of dead wood (branches and tree trunks) that provide bird perches and invertebrate habitat as a food source.

Herpertofauna (lizards) may also use green roof areas and would be assisted in their establishment by certain vegetation types, basking rocks and logs. The movement of herpertofauna may be possible between nearby roof expanses. Initially these species may need to be transplanted to green roofs. Inevitably these systems could represent an 'island' habitat, protected from predators, with specifically modified micro-climates to provide refugia. These populations would have to be carefully managed to prevent genetic bottlenecking.

TAXA	DISTRIBUTION	REFUGE	FORAGE
Birds	• View the context of flyzones in terms of building height and proximity to street trees or open spaces	• Dense shrub environments • Consider artificial roosts and nest sites for birds of prey	• Dense shrub environments on sunny edges provide dense foliage and fruiting • Dead wood for perching and invertebrate sources • Flowering natives for nectar feeders • Consider artificial-feeders with species specific access
Reptiles	• Any physical connection between rooftops may also encourage rodents, unless they can be controlled • Large or connected rooftops may be appropriate to provide refugia, but populations will need to be managed to prevent genetic bottlenecking, and this will require permits etc to handle threatened species	• Rock piles and log stacks • Dense low growing shrub environments on sunny edges • Dense grasses - flaxes and toetoe	• Habitats that favour insects • Year round low and prostate fruiting shrubs
Invertebrates	• Flight dependant	• Rock piles and log stacks • A lack of structural plant diversity on green roofs will effect diversity of insect populations	• Dense shrub environments • Rock piles and log stacks

Table 2: Green roof habitat enhancement

3.3 PLANTING

Plants attenuate significant volumes of stormwater by interception of rainfall and evapotranspiration . Depending on the depth of growing medium, and potential for irrigation and maintenance, green roofs can support a wide variety of vegetation types (Dunnett & Clayden 2007). Characteristics of vegetation types used in green roof systems are:

- Drought tolerance.
- Shallow root systems.
- Regenerative qualities.
- Resistance to direct radiation, frost and wind.

In many instances the local flora may be unsuitable for green roof situations, especially for extensive systems, because of the extreme environmental conditions encountered. Therefore, more appropriate species for the conditions may be coastal, cliff dwelling, or dry turfs that are generally common to harsh climatic zones with limited soil, water, and nutrients. Green roofs therefore provide opportunities for unusual plant combinations.

Vegetation selection will influence how a green roof performs. Different physical plant shapes (morphology) and seasonal changes (phenology) can have a considerable effect on stormwater management. Observations suggest that hairy leaves hold more water than smooth and that horizontal leaves hold more than angled. Grasses having shallow dense rooting systems are highly effective at taking up water (Dunnett & Kingsbury 2008).

Plants that tolerate droughts by storing water in above-ground tissues, or that have thick waxy cuticles to reduce water loss (e.g. succulents) are common on extensive green roofs. Sedums and Crassulas store carbon dioxide in their leaves during dark, cool hours, and close their stomata during daylight (photosynthetic) hours, reducing moisture loss. Tussocks have been successful on roofs around the world, with the adaptations of rolled leaves that reduce water transpiration losses and extensive root systems.

Green roofs can be extremely windy places, especially on taller buildings, and where wind is deflected or accelerated by adjacent hard surfaces (e.g., wind-tunnels). Most extensive green roof plants will be less than 300 mm height; suitable plants will either have a fine leaf

Image source above: http://www.flickr.com/photos/80081757@N00/5850122
Below: http://www.ecosalon.com/high-tech-green-roof-technology-in-architecture/

Figure 26: A wide variety of planting schemes are possible on green roofs, from urban forest to vegetable garden

Figure 27: Green walls provide further visual and ecological diversity to city environments and opportunities to capture and treat stormwater

structure that disperses wind (e.g. *Poa* grasses and *Festuca* tussocks), a compact form of tightly-bound interlocking branches with small leaves (e.g., prostrate *Coprosma* and *Muehlenbeckia* species) or are anchored at internodes (e.g. *Selliera radicans* and *Leptinella* species).

PLANTING ESTABLISHMENT

Rooftops are diverse environments, with unique aspect, height, reflecting surfaces, and wind dynamics. Planting schemes should therefore be specific to each roof top. The following are some of the planting design parameters that aid plant establishment:

- Moisture stress is determined by substrate depth, moisture storage, underlying thermal mass, duration and timing of shade, wind exposure (including discharges from air conditioners), and local climate. On sloped roofs the aspect and location influence moisture stress, with dryer areas towards the ridgeline and on north-facing aspects, and wetter areas near the eaves and south-facing roofs. Water storage can be improved through amendments to substrates and pre-fabricated reservoirs below substrates.
- A shallow substrate can only support specific plants. The plant lists provided in this document are suitable for extensive green roofs. The plants that occur on extensive roofs are only limited by substrate depths (affecting the load on rooftops) and microclimates.
- Plant mixes will generally include a high proportion of species that spread rapidly (~75% cover within 2 years), and a few species that are slow-growing. The latter may occur near access points.
- Plant diversity avoids the risk of plant failures across the extent of the roof, and will provide plants suitable for specific microclimates.

PLANT INSTALLATION

Plants can be applied to green roofs by several means, including pre-vegetated mats or blankets, cuttings, seed, or root plants, hydroseeding, or any combination of these methods. Planting must take into account microclimates on roof tops, with significant environmental variations caused by rain or sun shadows of utility structures, roof edges etc. Groups of plants will also create their own microclimate and can be grouped accordingly. Tall plants on exposed roofs need to be staked or secured.

In New Zealand most green roofs are established using plugs or small root trainers. Larger plants should be grown ahead in green roof substrates as standard propagation mixes have a very high organic component that is susceptible to shrinkage over time, may increase the weight of the roof, and reduce or slow root exploration into the green roof media.

A few New Zealand growers can supply pre-grown mats. These provide an 'instant' result, as do pre-grown modular systems which contain plants, substrate and drainage system.

USING THE PLANT LIST

The following plant list identifies native species suitable for light-weight (100 to 300 mm depth) non-irrigated green roofs in the Auckland environment. The list is not exhaustive and success will ultimately depend on site conditions and maintenance levels. Images of most plants can be seen on the NZ Plant Conservation Network (www.nzpcn.org.nz). When selecting plants it is important to note the following:

- The table identifies those species that have been observed over three year trials on University of Auckland green roofs with 50-100mm soil media depth (denoted as a double asterisk **) and over one year trials on the Waitakere Civic Centre and Landcare Research Tamaki campus buidlings with 100-150 mm media depth (denoted as a single asterisk *)
- The extreme environments of green roofs may require plants that occur outside of the Auckland Region (denoted as a hatch #) to provide the same environmental services and landscape values.
- Additional species for biodiversity appear at the end of the table. These may be integrated into gaps and edges, but are likely be too slow to establish or require too much additional maintenance to be considered for mass planting.
- Some plants are available in a variety of forms and leaf sizes. Generally the most prostrate and dense forms are preferred for green roofs as they are less susceptible to collar rot and require lower maintenance (as they suppress weeds).
- Some species have many available varieties and cultivars, e.g. manuka, coprosma, NZ iris (Libertia). Plants sourced from exposed, droughty sites, are more likely to perform well.
- The list includes plants suitable for shaded areas of roofs, and moister areas of roofs.

Figure 28: Green roofs can increase the perceived extent of open space in urban areas . China Image source http://www.flickr.com/photos/kafka4prez/41572708/

- Notes indicate special features, particularly with regard to maintenance, flower and/leaf colour, and growth rate.
- Maximum heights in natural soil conditions are given. Heights of the taller plants (e.g. Apodasmia similis, Haloragis erecta) are likely to be suppressed on rooftops.
- Frost tolerance has not been considered.
- The list includes species from outside the Tamaki Ecological District, in particular it includes species from offshore islands that have been trialed – local species may perform as well.
- All species can be found from specialist native plant nurseries; some are commonly propagated and have widespread availability.

GENUS	SPECIES	COMMON NAME	DESCRIPTION	TRIAL	HEIGHT (M)	SPREAD (M)	WATER TOLERANCE	SUN / SHADE	NOTES
TOP 40 SPECIES FOR EXTENSIVE GREEN ROOFS (100 TO 300 MM DEPTH) IN THE AUCKLAND REGION *** READ WITH ACCOMPANYING NOTES ***									
Acaena	Local native species	Piripiri	Ground Cover	**	0.05-0.10	1.00-2.00			Various coloured foliage (purple, red, green with attractive spikey balls of seed heads). Vigorous groundcover.
Anaphaloides	bellidioides	Everlasting flower	Ground Cover	*	0.15	0.5			White conspicuous daisies flower in summer. Main stems are prostrate and root.
Apodasmia	similis	Oioi, Jointed rush	Sedge & Rush-like		1.00	1.00			Very hardy and spread moderately slowly through rhizomes.
Arthropodium	Local native species	Rengarenga	Lily & Iris-like	*	0.20-1.00	0.20-0.75			White flowers (spring) and strap-like grey-green glaucous foliage. Frost tender. Coastal. Clump-forming
Astelia	banksii	Wharawhara	Lily & Iris-like	*	1.00	1.50			Fine silver flax-like leaves. Coastal. Clump-forming
Blechnum	penna-marina	Alpine hard fern	Fern	#	0.20	1.00			Forms a dense mat. Very hardy in both sun or shade. An excellent ground cover.
Calystegia	soldanella	Shore bindweed, rauparaha	Ground Cover	**	0.10	5.00			Coastal ground vine with large bright green leaves, deciduous with large mauve to pink flowers in summer.
Carex	pumila	Blue dune sedge	Sedge & Rush-like		0.30	2.00			Vigorous rhizome spreading sand sedge. Sunny well drained site
Carex	testacea	Orange dune sedge	Sedge & Rush-like		0.40	0.40			Fine leaved green-orange coastal tussock. Prefers sun and drier soils
Centella	uniflora		Ground Cover		0.10	1.00			Common hardy ground cover. Fast growing. Forms tough mats in lawns or rockery.
Coprosma	acerosa	Coastal coprosma	Ground Cover	**	0.40	1.00			Sprawling coastal plant with wiry orange branches, small green leaves and round fleshy fruit. Varying colours, height and density of branches from different eco-sourced plants.
Coprosma	brunnea		Ground Cover	#	0.40	1.00			Openly sprawling coastal ground cover. Blue berries amongst dark brown foliage.
Coprosma	perpusilla		Ground Cover		0.01	0.60			Grows in high montane grasslands and herbfields, forming mats in damper sites. Provide full sun and plenty of moist humus. Also consider C. petrei, as a slow-growing mat.
Dichondra	brevifolia	Mercury Bay groundcover	Ground Cover	**	0.01	1.00			Very flat ground cover suitable for a 'lawn' look. Coastal. Far-creeping and will crawl beneath Coprosma acerosa and amongst Libertia, so useful to colonise bare spaces.
Disphyma	australe	Native iceplant	Ground Cover	**	0.02	1.00			Coastal creeping succulent forming mats. Large white-pink-mauve flowers (summer). Frost tender. Self-seeding. Has been susceptible to near-complete dieback in the second year on two trial roofs.

Table 3: Green roof plant schedule

GENUS	SPECIES	COMMON NAME	DESCRIPTION	TRIAL	HEIGHT (M)	SPREAD (M)	WATER TOLERANCE	SUN / SHADE	NOTES
Doodia	australis	Pukupuku	Fern		0.30	0.50			Short creeping. Pink new fronds in the sun. Good pot plant. Very hardy fern in sunny, dry conditions. Was named Doodia media.
Einadia	triandra		Herb		0.10	1.00			An endemic coastal plant from throughout NZ. Bright red berries provide food for lizards and birds.
Festuca	actae	Banks Peninsula festuca	Tussock Grass	*#	0.30	0.40			Endemic to Banks Peninsular. Fine blue colour, with a graceful form.
Festuca	coxii	Chatham Island blue grass	Tussock Grass	**#	0.40	0.50			Fine, rolled blue-grey leaves with graceful seed heads. New plants will establish from seed. Outstanding survivor on two trial roofs.
Festuca	matthewsii	Blue grass	Tussock Grass	*#	0.30	0.30			Keeps good colour and vigour with graceful seed heads.
Ficinia	nodosa	Knobby club rush, Wiwi	Sedge & Rush-like	*	1.50	1.50			A fine green-orange sedge that forms fountain like clumps on dry rocky coastal headlands. Self-established on trial greenroofs. Formerly called Isolepis nodosa.
Hebe	obtusata	Waitakere coastal hebe	Shrub	*	0.50	1.00			Prostrate habit; bright-green leaves. 'Bottle brushes' of mauve flowers (summer-winter). Found on windy cliff sites on Auckland's West Coast.
Hibiscus	diversifolius		Shrub	#	1.50	2.00			Select the prostrate form. Large yellow flowers . Coastal. Frost tender.
Hydrocotyle	Local native species		Ground Cover		0.10	1.00			Far-creeping ground covers with soft herbaceous foliage. Appear tropical
Leptinella	dioica	Shore leptinella	Ground Cover	*	0.10	1.00			Also *L. perpusilla*. Feathery, soft spreading groundcovers suitable as mown lawn alternatives. *L. dioica* is extremely variable. Coastal, including margins of saltmarshes, and inland up to 1000 m a.s.l..
Leptospermum	White Prostrate	Manuka	Ground Cover	#	0.50	1.50			Very attractive weeping habit. White flowers (spring and autumn). Ensure the most prostrate forms are selected from the driest sites.
Leptostigma	setulosa		Ground Cover	**	0.10	0.50			Small green leaves creates slight mounds to 0.1 m high. Vigorous and resprouts from summer dieback. Tolerant of wide range of conditions.
Libertia	peregrinans	Native iris	Ground Cover	**	0.25	0.40			Spread slowly by rhizomes. Quite rare in the wild, It is found growing in open poorly draining ground under scrub or on coastal dunes and cliffs.
Lobelia	anceps	Punakuru	Ground Cover		0.10	0.30			Dark green creeping foliage. Light pink-mauve flowers (spring-autumn). Easy to grow in sun and drier soils.
Microlaena	stipoides	Rice grass	Grass		0.30	1.00			Finer-leaved grass than *M.avenacea*. Vigorous gowth. Turf forming. A taller lawn alternative than other species; may be perceived as 'weed-like' in mixed plantings.

GENUS	SPECIES	COMMON NAME	DESCRIPTION	TRIAL	HEIGHT (M)	SPREAD (M)	WATER TOLERANCE	SUN / SHADE	NOTES
Microsorum	pustulatum	Hounds yongue	Fern		0.30	1.50			Fern with distinctive thick glossy bright green leaves. Slow to establish and spread. Climbs over rocks and up trees.
Muehlenbeckia	axillaris	Pohuehue	Ground Cover	**#	0.15	1.00			Forms a dense dark green mat of interlaced branches with small white/green flowers (summer) and fleshy opaque fruits.
Oplismenus	hirtellus	Basket grass	Grass		0.15	3.00			Prostrate grass with a loose spreading habit. Will tolerate light foot traffic.
Pimelea	Local native species	Toroheke, NZ daphne	Ground Cover	**	0.15	1.00			Pointed grey to green foliage. Choose the most prostrate forms to achieve a dense, weed- and wind- resistant mat. Clusters of white flowers (spring-autumn).
Polytrichum	juniperinum	Moss	Moss	*	0.01	0.20			Prefers sheltered and shady conditions but is tolerant of more open sites as well.
Pteris	tremula	Turawera	Fern		1.00	1.00			Easy to grow vigorous fern, often colonises under decks or in rockeries. Good hardy pot plant.
Rubus	x Barkeri	Bush lawyer hybrid	Ground Cover	#	0.15	2.00			Reddish-brown trifoliate foliage on this sterile hybrid makes a good groundcover. Vigorous and slightly prickly.
Scandia	rosifolia	Native angelica	Shrub	*	1.00	1.50			Aromatic glossy dark green foliage. Dill-like flower head. Probably stunted to <0.5 m height on green roofs.
Selliera	radicans		Ground Cover	**	0.03	2.00			Small, strap-like, bright green foliage develops lush, carpet-like undulating 'lawns'. Variable leaf size and shape. White scented 7 to 10 mm flowers (summer). Drench with salt water to control weeds.
Tetragonia	implexicoma		Ground Cover	*	0.10	1.00			Semi-succulent bright green leaves turn yellow/red when stressed. Large red berries. Coastal. Prefers some shade.
Trisetum	arduanum		Grass		0.30	0.30			A coastal plant that likes to be on cliffs. Attractive flower heads. Foliage usually hangs down slopes of cliffs. Uncommon for the Auckland area.
ANNUAL OR SEMI-ANNUAL SPECIES SUITED FOR LIVING ROOFS OR ROOFS PLANNED FOR SUMMER DIEBACK (SEASONAL BARE GROUND)									
Crassula	sieberiana		ground cover	*	0.05	0.10			Green feathery herb forming dense patches in winter and spring; insignificant flowers and fruit. Some other native crassulas are perennial.
Haloragis	erecta	Toatoa	Herb		1.00	1.00			Spreading bright green bushy species. Very hardy, fast growing but probably best treated as an annual on green roofs.
Hibiscus	richardsonii	Puarangi	Herb		0.50	0.30			Previously known as *Hibiscus trionum* this yellow flowered Mercury Islands form is now recognised as the true native species. Easy to grow.

GENUS	SPECIES	COMMON NAME	DESCRIPTION	TRIAL	HEIGHT (M)	SPREAD (M)	WATER TOLERANCE	SUN / SHADE	NOTES
Wahlenbergia	albomarginata	NZ bluebell	herb	*	0.15	0.30			Attractive mauve flowers on thin stalks above a dense mound of vegetation; spreading
ADDITIONAL SPECIES WORTH TRIALING FOR BIODIVERSITY									
Anemanthele	lessoniana	Gossamer grass	Grass		0.80	1.30			Forms large, fine-leaved tussocks. Fine pink feathery flower head. Will self-establish after initial planting.
Asplenium	haurakiense	Hauraki asplenium	Fern		0.50	0.50			Although best in shade it is an incredibly tough fern for those hot dry sunny places that very few ferns can survive in. It loves rich guano or compost and makes a great pot plant. Coastal rock dweller it forms a dense clump of hundreds of fronds.
Asplenium	obtusatum		Fern		0.30	0.40			A coastal fern. Lush green prefers dry dappled shade. An excellent pot plant.
Atriplex	cinerea	Silver salt bush	Ground Cover		0.70	2.00			Low spreading dense bush. Silvery grey foliage. Coastal. Keep well pruned.
Bromus	arenarius		Grass		0.40	0.40			This is a rare annual grass with glaucous leaves with soft hairs all over it. The flower heads are delicate and drooping.
Carex	hectorii		Sedge & Rush-like	#	0.20	0.30			An attractive alpine Carex with blue-green foliage. Shortly rhizomatous, loosely tufted sedge of open damp ground in tussock grassland, or fringing cushion bogs, tarns and ponds.
Carex	muelleri		Sedge & Rush-like	#	0.40	0.20			This is an attractive erect rather brick coloured sedge. Slow growing and has good landscaping potential.
Celmisia	major		Herb		0.20	0.20			Normally Celmisia are alpine plants, but this form is coastal. Full sun, rocky well drained situation. Not always available.
Centipeda	Local native species	New Zealand sneezewort	Herb		0.01	0.30			An opportunist herb that colonisers the beds of freshly drained dams and ponds . It is shortlived but seeds rapidly to recolonise other damp areas. Recently recognised as a distinct species endemic to New Zealand.
Cheilanthes	Local native species	Rock fern	Fern		0.10-0.2	0.2-0.3			Small dark green fern with linear fronds. Short creeping. Frost hardy. Lives in full sun on dry rocks. Seldom available.
Chionochloa	bromoides	Coastal tussock	Grass		0.50	0.75			Northern coastal tussock with lax flower spikes. Normally hangs on cliffs in full sun or under shade of Pohutukawa.
Chionochloa	conspicua	Hunangamoho	Grass	#	1.00	1.00			Tall open flowering spike. Broad Toetoe-like foliage. Sun or light shade and dry to moist soils.
Crassula	ruamahanga		Ground Cover		0.04	0.50			An opportunistic species which can be expected to occur in any suitably damp, open habitat.

GENUS	SPECIES	COMMON NAME	DESCRIPTION	TRIAL	HEIGHT (M)	SPREAD (M)	WATER TOLERANCE	SUN / SHADE	NOTES
Dichelachne	inaequiglumis		Grass		0.60	0.40			When in flower this grass looks beautiful due to its grace and detail. Ours is sourced from Waitakere and it is a threatened species for the Auckland area.
Disphyma	papillatum	Chatham Is. iceplant	Ground Cover	#	0.02	1.00			Small-leaved iceplant from the Chatham Islands with a dense habit. Ideal for rock gardens or hanging over walls.
Elymus	solandri	Blue grass	Grass		0.20	0.40			Stunning blue-grey foliage that forms wide clumps. Coastal.
Epilobium	Local native species		Herb		0.70	0.50			Several species will tolerate rooftop conditions. Rapid growing and selfseeding the population will fluctuate.
Eryngium	vesiculosum	Sea holly, coastal eryngo	Herb	#	0.10	0.50			Matt green groundcover with prickly leaves. Dense and fast-growing.
Euphorbia	glauca		Herb		0.50	2.00			Colour varies from pastel green to vivid blue-grey foliage. Coastal plant of ecological importance with a wide creeping habit. The species is now in serious decline due to coastal development and weed competition.
Festuca	novae-zelandiae	Tawny tussock	Grass	#	0.40	0.40			Fine-leaved tufted, tawny tussock. Spiky in habit.
Fuchsia	procumbens	Creeping fuchsia	Ground Cover		0.15	2.00			Creeping habit will cover large areas prefers light shade. Large pink berries (autumn). Good hanging pot plant.
Geranium	Local native species		Herb		0.15	0.5-1.0			Branches trail along the ground bearing small white/pink flowers. Best for natural plantings or collections.
Gonocarpus	Local native species		Herb		0.20	1.00			Hardy mat-forming groundcovers that tolerate impoverished soils. Often develop an intense red colour.
Hebe	elliptica prostrate		Ground Cover	#	0.30	1.50			A low coastal Hebe suitable for the edge of garden borders.
Hebe	pimeleoides		Shrub	#	0.70	1.00			Occurs in exposed rocky outcrops and cliff faces. Small bushy shrub growing up to 70cm tall. Inflorescences have between 4 and 12 flowers. The flowers are mauve but fade to pale pink (or almost white) after pollination.
Hebe	speciosa		Shrub		1.00	0.80			Dark green foliage. Magenta flowers in winter. Grows mainly on West Coast headlands and needs windy, sunny, dry sites. A threatened species.
Hebe	treadwellii		Shrub	#	0.50	0.50			Alpine species with dark green leaves. Occasional white flowers. Grows naturally west of the main divide in subalpine shrubland. Synonym Hebe brockiei.

GENUS	SPECIES	COMMON NAME	DESCRIPTION	TRIAL	HEIGHT (M)	SPREAD (M)	WATER TOLERANCE	SUN / SHADE	NOTES
Heliohebe	hulkeana		Shrub	#	0.50	1.50			Strikingly handsome long lavendar flower spikes set against glossy purple-green foliage. Spreading shrub from the rocky windswept Seaward Kaikoura Ranges.
Hypericum	aff japonicum		Herb		0.01	0.40			This is an unclassified species from the Central Plataeu area. It is a collectors plant and may be one of New Zealands rarest plants. Limited avaliability.
Lachnagrostis	billardierei	Wind grass	Grass		0.30	0.30			A blue/green grass with dense fairy-land like flower heads. Fast growing and hardy. Usually found on sand dunes and cliffs.
Lachnagrostis	filiformis	Wind grass	Grass		0.50	0.30			This is a grass that's good for natural plantings as it will seed everywhere and grows rather sparsly. However it is a grass that is being pushed out of its habitat in Auckland and should be spread around.
Lagenifera	montana		Herb	#	0.01	0.30			A rare species of daisy that forms dense patches in friable soil in shady areas. Thin light green leaves with tiny white flowers. Grows reasonably well in warmer areas but does not like competition.
Lepidium	oleraceum	Cooks scurvy grass	Herb		0.30	0.40			Edible herb. White flowers, and glossy serrated leaves. Coastal. Demands high nutrients such as guano.
Leptospermum	wairere	Manuka	Ground Cover	#	0.30	0.75			Prostrate manuka. Single pale pink flowers (summer). Cascading habit.
Lobelia	"Woodhill"		Ground Cover		0.01	1.00			A recently described form from Woodhill. Previously included in the genus Pratia. A rapid spreading groundcover with attractive white flowers and pink fruit.
Ophioglossum	petiolatum		Herb		0.15	0.30			A rare summer-green relative to ferns. Vulnerable to slugs and pests . Rather attractive. Usually found around bogs and swamps.
Pachystegia	insignis	Marlborough rock daisy	Shrub	#	0.50	0.50			Bold silver/grey foliage. White daisy-like flower (summer). Needs good drainage
Paspalum	orbiculare		Grass		0.40	0.30			A rare non invasive species. Soft green clumping leaves with slightly red bases. Does not self seed everywhere.
Pellaea	rotundifolia	Button fern	Fern		0.30	0.30			Drought tolerant but grows better in moist free draining soil. Slow creeping habit.
Pellaea	falcata		Fern		0.40	0.40			Drought tolerant but grows better in moist free draining soil. Slow creeping habit.
Peperomia	blanda		Herb	#	0.30	0.40			A rare species from the Kermadec Islands. Larger than other native species. Light green leaves 2x 3 cm, with flower spikes up to 5 cm long. Fast growing and easy but rather cold sensitive. Very tropical and attractive.

GENUS	SPECIES	COMMON NAME	DESCRIPTION	TRIAL	HEIGHT (M)	SPREAD (M)	WATER TOLERANCE	SUN / SHADE	NOTES
Peperomia	urvilleana		Herb		0.15	0.30			Shiny, succulent leaves. Slow spreading. Frost tender. Coastal rock faces in shade.
Pittosporum	cornifolium	Tawhiri karo	Shrub		2.00	1.00			Open habit. Interesting leaf arrangement (whorls). Often epiphytic on trees or on rocks. Has sweet scented red flowers and the open capsules are orange. Fast growing.
Pittosporum	pimeleoides		Shrub	#	1.50	0.40			This is a compact column forming shrub with dense light green leaves and very sweet scented flowers. A threatened species from Northland.
Plantago	Native species	Native plantain	Herb		Flat-0.1	0.06			Compressed forms making interesting low rosettes. Self seeds. Does well in rockery.
Poa	cita	Silver tussock	Grass		1.00	1.00			Graceful silver tussock grass. Thrives in poor soil and dry sunny conditions.
Pyrrosia	eleagnifolia	Leatherleaf fern	Fern		0.10	0.30			Creeping epiphyte on tree trunks, branches, or on coastal rocks. Thick, simple fronds and very hardy.
Raoulia	hookerii	Scabweed	Ground Cover	#	0.01	0.30			Alpine species. Silver foliage. Needs good drainage and full sun in a rock garden.
Scleranthus	biflorus		Herb	#	0.10	0.50			Intriguing, conspicuous bright yellow-green mounds on rocks and coastal cliffs. Provide full sun and gritty soil. It is not a moss.
Sicyos	aff. australis		Herb		5.00	5.00			This is the native cucumber from Auckland's offshore Islands. It is fast, rare and an interesting annual. Has spiny barbed fruit.
Sonchus	kirkii	Puha	Herb		1.50	0.50			Broad silver-green edible foliage. Very fast growing. Bears yellow daisy-like flowers. Threatened
Trisetum	antarcticum		Grass		0.40	0.40			An attractive rare grass for difficult conditions like rock gardens or coastal areas. May not get to same size in cultivation as in the wild.
Vittadinia	australis		Herb		0.15	0.20			A glaucous leaved plant that has little white daisy flowers. A threatened species. Usually found by coast.
Zoysia	minima		Grass		0.05	1.00			This grass is good for species enhancement projects and erosion control. Spreads by a robust rhizome.

3.4 OPERATION & MAINTENANCE

Regardless of the type, all greenroofs will require initial watering and occasional fertilization until the plants have fully established themselves. Irrigation at least once a week may be required in the first six months, depending upon the type of roof membrane and water requirements of the plant material (Kidd 2005).

Once installed, an extensive green roof's maintenance requirements are minimal. Extensive green roofs would normally only require annual visits to remove wind-blown litter, check fire breaks and drains and in some cases remove unwanted colonising plants.

A key risk, especially in the extensive greenroofs, is differential interpretation of what 'poor growth' constitutes. Maintenance regimes should apply a minimum 18 month duration (two growing seasons) with budget for monthly visits during the first 6 months, then quarterly visits, will identify potential problems.   A maintenance contract is ideally linked to a person on site who will observe the roof on a weekly or fortnightly basis, especially during summer when timing of supplementary irrigation may be important to ensure plant survival.

Table 3 below illustrates a potential programme for the operation and maintenance of a green roof. Specific periods between intervention will vary according to the climatic conditions of the roof and the proposed planting scheme. The extent of maintenance will also be guided by the proposed final aesthetic and function, either maintained in a 'lush' and structured condition or left to allow a selective process where the hardiest species survive and repopulate.

EXTENSIVE GREEN ROOF													
"SOFT" LANDSCAPE MAINTENANCE SCHEDULE													
MAINTENANCE (AS REQUIRED)	GROWING SEASON												AT COMPLETION
	SPRING			SUMMER			AUTUMN			WINTER			
	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	
PLANTS													
TRIMMING AND PRUNING													
WEED CONTROL													
WATERING		WEEKLY											
FERTILISER													
REPLACEMENT													
OVER SOWING													
OTHER													
LITTER REMOVAL													
CHECK FIRE BREAKS													
CHECK DRAINS													

Table 4: Green roof operation and maintenance programme

4.0 RAINGARDENS, TREE PITS, AND PLANTER BOXES

Bioretention devices such as raingardens, tree pits and planter boxes can be integrated seamlessly into existing landscapes. Alternatively, these systems can openly demonstrate their function through revealing water and wetland vegetation within hard landscapes.

Raingardens and tree pits are generally found adjacent to areas of diffuse stormwater flows or at the outlet of an overland flow path. Planter boxes generally receive point source runoff from rooftops or adjacent hard surfaces. In all cases it is important to effectively address stormwater quality and quantity function while responding to objectives for landscape and ecology.

4.1 LANDSCAPE

The means to integrate bioretention devices into the landscape can be achieved through the following means (refer figures 30 and 31):

- Grading to incorporate raingardens in terraces or mid slopes. Raingardens also have the potential to reinforce existing landforms and/or reference visible landforms nearby, in this way enhancing the experience of the site.
- Devices may incorporate existing vegetation or reference existing planting schemes. Where constraints prevent particular species from being used, it may still be possible to emulate the qualities in form, colour and/or texture of plants.
- Respond to existing spaces by providing for suitable edges.
- Enhance connectivity by reinforcing corridors, axes, and views by the placement of bioretention devices, and allowing for crossing points over devices as necessary.

Other landscape objectives to be considered may include:

- Formalised edges to delineate travel-ways and the extent of maintenance such as mowing strips.
- Shade and cool adjacent spaces, cars and people, particularly where raingardens are located in car parks, footpaths and public paved space.
- Provide visual screening and glare reduction, e.g., car headlights.
- Enhance security where spikey, prickly, or sharp leaves are used.
- Enrich play areas with water fun and bright, lush wetland plants.
- Opportunities to organise and arrange outdoor space. For instance, L-shaped planter boxes can be used to create intimate seating areas, raingardens can separate spaces or provide a legible edge to an existing space, and tree pits can provide for human scale spaces beneath their canopy.
- Provide for rhythm and proportion in the landscape through repetition, shape, and scale of arrays of bioretention devices.
- Integrate appropriate traffic control using physical barriers such as bollards, broken kerbs, planting etc to prevent physical access by cars. Visibility from road to footpath must also be considered with pruning of trees and installation of mass planting less than one metre high.

Figure 29: Raingardens enhance the street amenity while also giving cues for slower vehicle travel

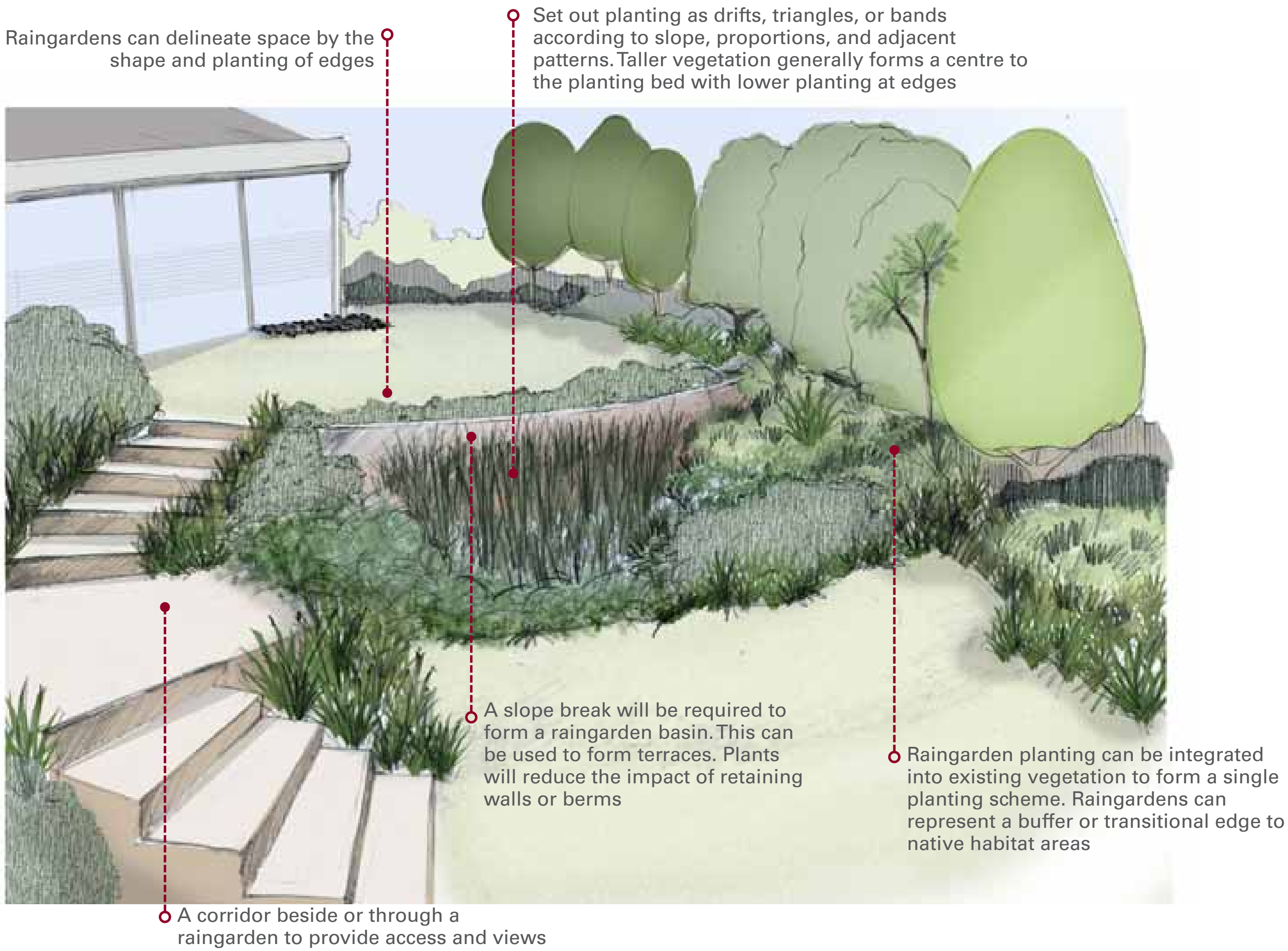


Figure 30: A raingarden in a private yard forming spaces and integrating planting schemes

- Responses to adjacent architecture, including appropriate reference of form, materials, and scale.
- Complement building materials or forms.
- Screen undesirable views.
- Integrate within built forms (e.g. atriums, courtyards) providing for cross-over between building and landscape spaces.

An alternative to integrating bioretention devices into the landscape is to create deliberate features that reveal water elements, wetland plants, or water quality treatment processes. Devices can become an expression of ‘eco-technology’ via bands of regimented plants defined by hard engineering at edges and divides. Water features can add a playfulness to the landscape with rivulets, channels, cascades, and splash pools.

Figure 31: Raingardens integrated with urban environments

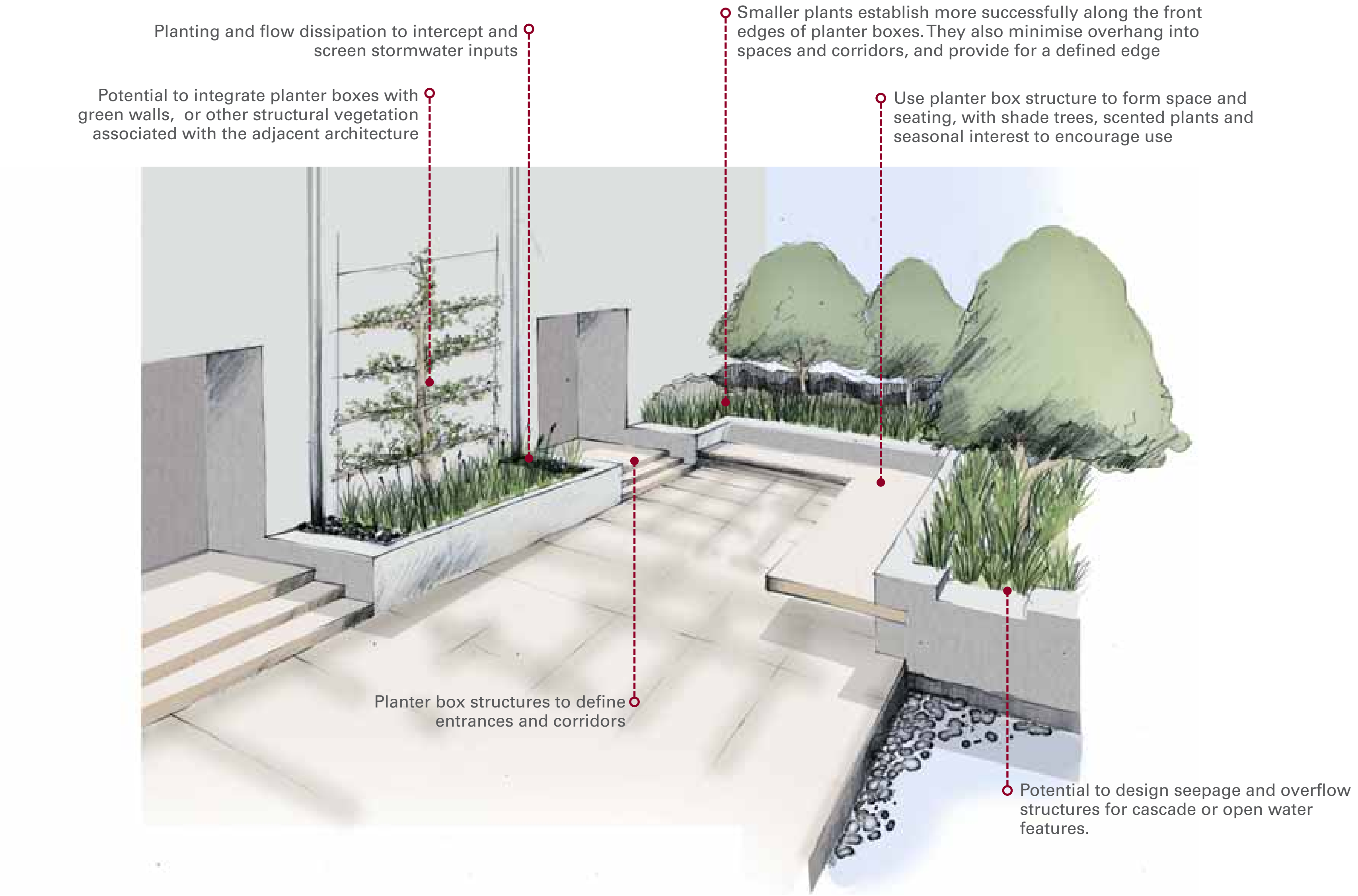


Figure 32: Potential for stormwater planter boxes to contribute to the amenity of a building facade

4.2 ECOLOGY

The ecological values for rain gardens, planter boxes and tree pits is limited by size, extreme microclimates, and isolation within hard surfaces. However these devices may represent a refuge for urban wildlife and a means to promote native species dispersion from outside the city into urban parks. This is particularly true of bird species that may alight in the canopy.

There are a number of opportunities to maximise ecology values for rain gardens, planter boxes and tree pits including (refer figure 33):

- Diverse assemblages of native plant species.
- Multiple tiers of planting, from ground cover species to canopy and emergent trees, providing a range of habitat niches of cover and browse. Multi-tiered planting can also form microclimates to accommodate species that are sensitive to climatic extremes.
- Include plants that will provide food for birds and insects all year round.
- Incorporate threatened plant species if conditions are appropriate and there is a means to support their ongoing population and genetic diversity.
- Incorporate rocks or driftwood into the rain garden to provide habitat for lizards. Rotting logs, twigs and leaves provide habitat for both insects and lizards.
- The potential for devices to form a transitional edge to existing vegetation and reduce the climatic edge effects to that system. In such cases it is also important to consider the existing hydrology of adjacent vegetation and ensure this is not impacted by stormwater collection in the device.

Although a single toetoe or tree may represent the habitat and home range for a skink, it may be inappropriate to intentionally disperse any skink species to these devices. However, a bioretention device adjacent to a park may provide access to other suitable habitat and therefore potential for broader distribution of individuals and populations.

TAXA	DISTRIBUTION	REFUGE	FORAGE
Birds	• Canopy and emergent trees as perches, where possible adjacent and connected to street trees • Attract frugivorous birds with year round fruiting trees	• Canopy and emergent trees for roosting • Mid-canopy trees for nesting • Dense shrub environments on sunny edges for safe refuge • Potential for mounds within road devices to act as loafing or breeding areas	• Year round food supply, and overlap of native tree fruiting • Structural plant diversity for insectivorous birds • Dense shrubs on sunny edges for dense foliage and fruiting • Flowering natives for nectar feeders
Reptiles	• Gardens in the middle of streets may be inappropriate for threatened species • Provide for lizards as appropriate, based on the potential to access other remnant habitat areas to avoid a genetic bottleneck • Corridors can be a hedgerow, or a line of refuges such as wooden disks or rocks	• Rock piles and log stacks • Dense low growing shrub environments on sunny edges • Manuka copses • Dense grasses, e.g. flaxes and toetoe • Developed leaf litter under canopy	• Habitats that favour insects • Year round low and prostate fruiting shrubs
Invertebrates	• Planted corridors can provide links for non-flying invertebrates to complete their life cycle, especially to stream environments	• Rock piles and log stacks • Structural plant diversity to optimise ecological niches and leading to dense and diverse leaf litter	• Structural plant diversity to optimise ecological niches and leading to dense and diverse leaf litter • Dense shrub environments • Rock piles and log stacks

Table 5: Raingarden, tree pit and planter box habitat enhancement

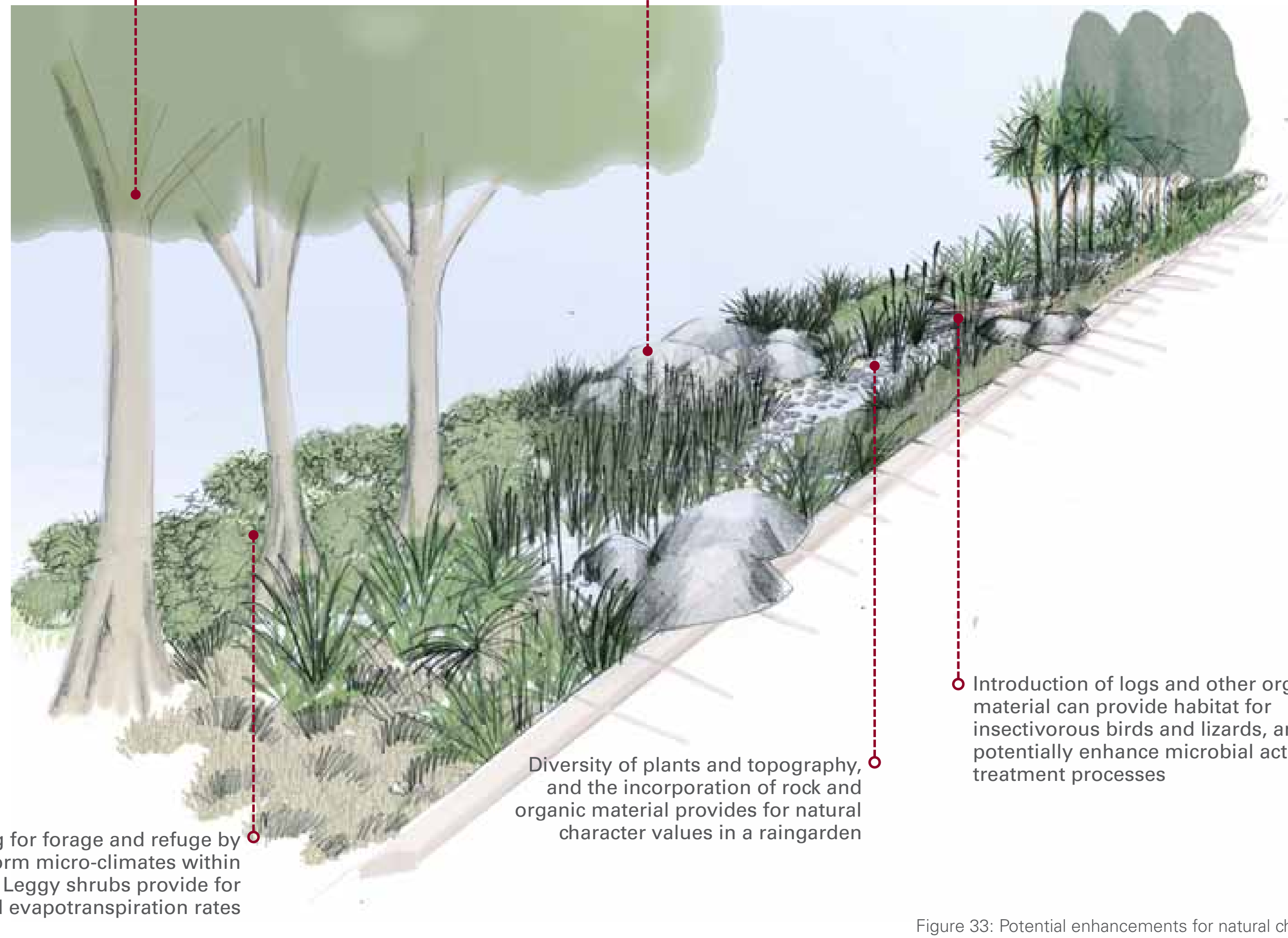


Figure 33: Potential enhancements for natural character values and habitat in raingardens

4.3 PLANTS

Raingarden soils in New Zealand vary from raw sands to heavy clay loams depending on permeability requirements. Specified permeability rates vary from 200mm/day to 500mm/hour dependant on the target contaminant. For example, particulate Zn is rapidly removed and therefore high permeability substrates are effective. Where nitrogen is the primary contaminant, increased contact time with soils requires a lower permeability.

Plants in raingardens, tree pits, and planter boxes should be chosen for their ability to tolerate a range of moisture conditions, and where possible a range of sun to shade conditions. These species should also be able to tolerate silt on their leaves and inundation of sediment at their roots. The plants most likely to fulfil these criteria are those found naturally in fluctuating wetlands and stream edges. Raingarden soils increasingly have increased permeability rates, requiring plant species tolerant of free-draining soils. Plants with deep root systems will have a particular advantage.

Substrates for planting should be at least 300mm deep for grasses, increasing to 600mm for shrubs, and 1000mm for small trees. Large trees also benefit from shallow soil layers beneath paving areas to provide for the spread of surface roots.

Plant selection and set-out for raingardens, tree pits and planter boxes should consider:

- In the lowest point of devices allow for plants that can tolerate frequent inundation to levels deeper than 200mm.
- Provide higher density planting in areas that are vulnerable to erosion or damage by people or vehicles.
- For stormwater inlets areas, provide for plants that are tolerant of sediment inundation and have thickly spreading rhizomous roots to prevent preferential flow paths in soils. These plants should also fall flat or part their leaves to prevent impediments to flow (spreading rather than clumping). Plants should be placed far enough from the inlet to avoid obstruction.
- Edges should have low growing vegetation to retain a distinct and maintainable edge. Edge species should be tolerant of roadway splash, temperature extremes, and other constraints relating to adjacent land use.
- Plants should be spaced as appropriate to cover any bare soil areas within eighteen months, to prevent erosion and optimise microbial activity.

Figure 34: Raingardens provide opportunities for diverse plant assemblages from both wet and dry environments

- Trees and shrubs in rain gardens increase interception and evapo-transpiration.
- Larger trees with extensive root systems should not be planted above existing infrastructure pipes, or where future access is an issue.
- Space trees a reasonable distance apart or prune branches to allow for dense groundcover plant growth.
- Large-leafed deciduous trees should be avoided unless autumn maintenance ensures fallen leaves do not suppress groundcover or block outfall structures.
- Long lived or expensive species should be considered only where the life of the device allows for them.

- Apply erosion control matting until plants establish.
- Plant in accordance with irregular distribution of flows i.e. take account of individual or groups of inlets, and low points within the device.
- Plants must be able to tolerate the duration of ponding without rotting (oxygen supply to plant roots is reduced after a day of ponding).
- Plants adjacent to footpaths should not form an obstruction.
- Plants beside roadways should provide for driver visibility (<1m heights adjacent to footpaths).
- There may be minimum plant heights to prevent glare from vehicle headlights.
- If there are likely to be coarse sediment loads, there should be a pretreatment area or filter zone within the device.

Figure 35: Pedestrian structures provide access over raingardens and an opportunity to view planting

The accompanying plant lists are divided by plant size (groundcover, shrubs and trees). It is important raingardens maintain a dense groundcover to slow water flow and avoid erosion of the surface. This means trees will usually need to be pruned to minimise shading of groundcover (lifted 2 to 2.5 m height and/or thinned)

The plant list includes some groundcovers under 100mm in height. These are potential replacements for filterstrips or edges. They can also be used as 'fillers' in raingardens with sparser tall plants. Do not use these groundcovers where sediment loads are high.

All the plants within the lists are native species. Care must be taken in selection of non-native plant species, as some may be weeds in the New Zealand environment. The use of native plants and eco-sourced material is particularly important where raingardens are near, or upstream of, natural areas.

Additional species for biodiversity appear at the end of the table. These can be integrated into gaps and edges, but are likely be too slow to establish or require too much additional maintenance to be considered for mass planting.

Figure 36: Tree planting adds further treatment potential to a raingarden, while also adding structural diversity, overhead canopy, and vertical elements in the landscape

GENUS	SPECIES	COMMON NAME	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES	INUNDATION – DURATION AND DEPTH
UP TO 1 METRE								
Baumea	tenax	Bumblebee nut sedge	Sedge	1.00	1.50	☀ ⛅	Slow spreading to form tufts in low fertility bogs and scrub. Rigid, wiry dull-green foliage.	100mm
Blechnum	minus	Swamp kiokio	Fern	0.40	1.00	☀ ⛅	Similar to Blechnum novae zelandiae but smaller and normally found in damp to swamp conditions.	Periodic 100mm
Blechnum	novae-zelandiae	Kiokio	Fern	1.00	2.00	☀ ⛅ ☁	Very hardy. New fronds pink in the sun. A popular fern for revegatation and ornamental plantings	Periodic100mm
#Blechnum	penna-marina	Alpine hard fern	Fern	0.10	1.00	☀ ⛅ ☁	Forms a dense mat. Very hardy in both sun or shade. An excellent ground cover.	Periodic 100mm
Carex	flagellifera		Sedge	0.50	0.75	☀ ⛅	Tussock grass with fine green foliage. Grows in sun and shade. Flowering stems lengthen when seeds ripen.	Periodic 100mm
Carex	gaudichaudiana		Sedge	0.30	1.00	☀	A highly variable species with a densely tufted, creeping rhizome. Requires moist, open situation. Forms thick swards.	Periodic 300mm
Carex	lessoniana	Rautahi	Sedge	1.00	2.00	☀ ⛅	Green tussocks with a wide-creeping rhizome. Damp or swampy ground. Ideal plant for stabilising stream banks.	Periodic 300mm
Carex	ochrosaccus		Sedge	0.75	0.75	☀ ⛅	Forms light green, robust tufts. Quick to establish. Often grows on stream banks.	Periodic 300mm
Carex	pumila	Blue dune sedge	Sedge	0.20	2.00	☀	Vigorous rhizome spreading sand sedge. Sunny well drained site	Periodic 100mm
Carex	virgata	Purei	Sedge	1.00	0.80	☀	Vigorous clumping fine-leaved, sharp edged, bright green tussock. A coloniser of dry and damp areas.	Periodic 300mm
Dianella	haematica	Turutu, NZ blueberry	Lily & Iris-like	1.00	1.50	☀ ⛅	A newly described species of Dianella which grows bigger than Dianella nigra and prefers it wetter than D. nigra usually does. Limited availability.	Periodic 100mm
Doodia	squarrosa		Fern	0.30	0.40	⛅	Hardy fern with pink new fronds, similar to Doodia australis but prefers damper conditions.	Periodic 100mm
Eleocharis	acuta		Sedge	1.00	1.00	☀	A wiry erect sedge with tufted rhizome. Widespread on pool, stream & lake margins. Ideal for mowing strip along side of wet areas.	300mm
Gunnera	Local native species		Ground Cover	0.05	0.5-1.00	⛅	Found on lake margins, swamps and stream sides. useful as a filler amongst other raingarden plants. Requires damp areas.	Periodic 300mm
Isolepis	prolifer		Sedge & Rush	0.30	2.00	☀	Light bright green fleshy sedge. Fast-spreading and prolific particularly suited for wetland areas.	100mm

Not naturally occurring in the Auckland Region

Table 6: Raingarden, tree pit, and planter box plant schedule

GENUS	SPECIES	COMMON NAME	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES	INUNDATION – DURATION AND DEPTH
UP TO 1 METRE								
Leptinella	dioica	Shore leptinella	Ground Cover	0.04	1.00		Fast growing. Small bright green fern-like leaf & useful as a filler amongst other raingarden plants.	Periodic 100mm
Leptostigma	setulosa		Ground Cover	0.05	0.50		Fast growing. Small bright green leaves it is useful as a filler amongst other raingarden plants or along mowing strip edge..	Periodic 100mm
Lobelia	angulata	Panakenake	Ground Cover	0.05	3.00		Probably NZ's most popular groundcover being vigorous growing and smothered in white flowers and red fruit. Ideal filling in amongst other plants in the raingarden.	Periodic 100mm
Machaerina	sinclairii	Tuhara, Pepepe	Sedge	1.00	1.50		Ideal in moist soil but tolerates a range of conditions. Attractive with graceful foliage and tall flowering spike (summer). Excellent as a substitute for Agapanthus.	Periodic 300mm
Paesia	scaberula	Scented fern	Fern	0.40	2.00		Vigorous growth once established forming broad sweeps of pale green fronds. Hardy. Tangly habit.	Periodic 100mm
1.00 TO 2.00 METRES								
Apodasmia	similis	Oioi, Jointed rush	Rush	1.50	1.00		Swamp plant of saline and freshwater habitats. Ideal garden plant, very hardy and slow creeping.	300mm
Astelia	grandis	Swamp astelia	Lily & Iris-like	2.00	2.00		Large 2m clumps, prefers swamps up to 50cm deep but grows in drier gardens. Olive green flax-like leaves.	Periodic 300mm
Baumea	articulata	Jointed twig-rush	Sedge	1.80	2.00		Best in very moist conditions but will tolerate both dry soil & deep water. Graceful 2m, brown seed heads in summer .	300mm
Carex	secta	Purei, makura	Sedge	1.50	2.00		Bright green swamp tussock. Can form a mop of foliage above a 1m trunk. Prefers damp sun but also tolerates dry shade.	300mm
Coprosma	tenuicaulis	Hukihuki	Shrub	2.00	1.00		Hardy shrub of wetlands and pakihi swamps. Prefers wettest soils but tolerates dry periods.	Periodic 100mm
Cyperus	ustulatus	Giant umbrella sedge	Sedge	1.50	2.00		Extremely sharp-edged swamp sedge. Fast growing with olive-green leaves. Ideal for wetland revegetation or provides security in urban areas.	300mm
Ficinia	nodosa	Knobby club rush, Wiwi	Sedge	1.50	1.50		A fine green-orange sedge that forms fountain like clumps on dry rocky headlands around the coastline. Tolerates periodic damp conditions. Formerly called Isolepis nodosa.	Periodic 100mm
Freycinetia	banksii	Kiekie	Vine	2.50	1.00		Scrambling vine with climbing stems and flax-like leaves. Prefers cool moist sites in heavy shade.	Periodic 100mm

GENUS	SPECIES	COMMON NAME	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES	INUNDATION – DURATION AND DEPTH
1.00 TO 2.00 METRES								
Gahnia	setifolia	Mapere - Common cutty grass.	Sedge	2.00	3.00		Large fine-leaved forest tussock. Easy to grow once established in dry to moist conditions. Foliage very cutting.	Periodic 100mm
Hebe	stricta	Koromiko	Shrub	2.50	1.00		Rapid growing and tolerant of harsh conditions. Capable of colonising bare areas.	Wet soil
Juncus	edgariae	Wiwi	Rush	1.50	1.00		Forms tight clumps from wiry stems. Tolerates extremes of wet and dry for short periods. Was known as Juncus gregiflorus.	100mm
Phormium	cookianum	Coastal flax	Flax	1.50	2.00		This is the coastal form and is very hardy in exposed conditions. Yellow flower stalk (2m) attracts tui in spring. Plant in drier areas or the centre of raingarden to avoid mower.	Periodic 100mm
Plagianthus	divaricatus	Salt marsh ribbonwood	Shrub	2.50	1.50		Coastal estuary plant will survive in soil wet from salt water. Forms a tangled reddish bush along shell banks. Extremely hardy and forms an elegant shrub in the raingarden.	Periodic 100mm
Pteridium	esculentum	Bracken	Fern	1.50	3.00		Bracken is best confined to revegataion projects as it can be invasive. Hardy in full sun.	Periodic 100mm
ABOVE 3 METRES								
Coprosma	propinqua	Mingimingi	Shrub	3.00	2.00		Swamp growing, divaricating shrub with a range of small-leaved forms. The female has blue fruit. Host plant for NZ mistletoe.	Wet soil
Corynocarpus	laevigatus	Karaka	Tree	8.00	4.00		Good specimen plant for tree pit. Grows along the coast and inland. Glossy bold foliage and orange berries.	Wet soil
Cyathea	medullaris	Mamaku	Tree Fern	6.00	5.00		Hardy, fast growing tree fern with 3m long fronds. Largest tree fern, often establishing in exposed sites and can tolerate a wide range of conditions.	Wet soil
Dicksonia	squarrosa	Wheki	Tree Fern	3.00	4.00		Fast growing in most conditions. Prefers a little shelter. Can form multiple slender stems.	Periodic 100mm
Gahnia	xanthocarpa	Tupari maunga	Sedge	3.00	3.00		Forms a large dark green clump. Cutting foliage. Drooping flower spikes to over 3m. Black nuts. Prefers swampy conditions.	300mm
Leptospermum	scoparium	Manuka	Tree	4.00	2.00		Abundant white flowers (spring). Very hardy. Sunny position, most soils. It is important to plant ‘eco-sourced’ stock as the species is highly variable. Select wetland forms for raingarden plantings.	Periodic 300mm

GENUS	SPECIES	COMMON NAME	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES	INUNDATION – DURATION AND DEPTH
ABOVE 3 METRES								
Libocedrus	plumosa	Kawaka	Tree	10m	4.00		Ornamental specimen tree similar to exotic conifers in appearance. Prefers sites with shelter and cool soil.	Wet soil
Olearia	solandri	Coastal shrub daisy	Tree	3.00	2.00		Excellent tree for the edge of tidal estuaries. Small yellowish leaves. Abundant fragrant flowers (autumn). Extremely hardy and can be kept clipped to a hedge.	Wet soil
Phormium	tenax	Harakeke	Flax	3.00	3.00		Red flower stalk (3-4m summer). Vigorous sturdy growth. Tolerates wet and/or coastal conditions. Plant in centre of raingarden to avoid mower.	100mm
Schefflera	digitata	Pate	Shrub	4.00	2.00		Best in moist conditions. Prefers cool shade but can handle full sun.	Wet soil
Syzygium	maire	Maire tawake	Tree	10m	4.00		Erect specimen tree develops aerial roots and buttressed trunk. Needs swamp conditions. White flower - red fruit.	Periodic 100mm
ADDITIONAL SPECIES WORTH CONSIDERING FOR BIODIVERSITY								
Carex	breviculmis	Short-culm sedge	Sedge	0.20	0.30		Attractive short green tussocks with a coarse leaf blade. Dry, shady areas. Coastal species.	Periodic 100mm
Centella	uniflora		Ground Cover	0.01	1.00		Common hardy ground cover. Fast growing. Forms tough mats amongst other plantings.	Periodic 100mm
Cortaderia	fulvida	Toetoe	Grass	1.50	2.00		Smallest of the Cortaderia's. 2m tall drooping flower spike (spring/summer). Ideal as filler to suppress weeds or 'en mass' as a feature plant.	Periodic 100mm
Deparia	petersenii		Fern	0.40	1.00		Creeping semi-deciduous fern. Easy to establish. Prefers semi-shade and slightly moist conditions.	Periodic 100mm
Gleichenia	Local native species	Tangle fern	Fern	0.50	1.50		Limited availability. Fronds wiry and interlacing. Creeping rhizome on dry barren soils under Manuka or wetter conditions amongst wetland plants.	Periodic 100mm
Glossostigma	elatinoides		Ground Cover	0.01	0.50		Can be submerged in water and useful as a filler amongst other raingarden plants.	Periodic 300mm
Hierochloe	redolens	Karetu, Holy grass	Grass	0.50	0.50		Plant for cultural purposes as it is used in traditional Maori weaving of satchets.	Periodic 300mm
Histiopteris	incisa	Water fern	Fern	1.00	2.00		Bracken-like in habit with soft glaucous fronds. Prefers open glades in scrub areas, swamps and streams. Summer green.	Periodic 100mm
Microlaena	stipoides	Rice grass	Grass	0.30	1.00		Vigorous growth forms a dense turf better suited to drier parts of a raingarden. Excellent for lawn, under trees, coastal bank or cliff sites.	Periodic 100mm

GENUS	SPECIES	COMMON NAME	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES	INUNDATION – DURATION AND DEPTH
TREE PIT SPECIMENS								
Alectryon	excelsus	Titoki	Tree	8m	4.00	☀ ⛅	Prefers rich soil, slightly frost tender. Attractive berries. Good specimen for street tree.	Wet Soil
Carpodetus	serratus	Putaputaweta	Tree	5.00	3.00	☀ ⛅	Attractive tree. Can be covered in small white flowers (summer). Prefers damp soils, sun or shade.	Periodic 100mm
Cordyline	australis	Cabbage tree	Tree	8.00	3.00	☀ ⛅	A classic New Zealand icon with 5m. single stem and round head. Scented flowers (spring). Plant in centre of raingarden to limit spread of old leaves.	Periodic 300mm
Dacrycarpus	dacrydioides	Kahikatea	Tree	35m	5.00	☀ ⛅	Superb specimen tree or in clumps, it can grow in damp and open sites. Adult foliage is a soft bluish-green. Important food source for birds.	Periodic 100mm
Knightia	excelsa	Rewarewa	Tree	20m	4.00	☀ ⛅	Narrow habit. Good specimen tree. Tui enjoy the red bottle-brush-like flowers (spring).	Wet Soil
Laurelia	novae-zelandiae	Pukatea	Tree	15m	3.00	☀ ⛅ ☁	Moderately slow growing. Attractive bright green leaves. Reddish new branchlets. Specimen tree for damp areas.	Periodic 100mm
Plagianthus	regius	Ribbonwood	Tree	8.00	3.00	☀	Graceful tree with delicate foliage which is semi-deciduous. Rare in Auckland but found on alluvial river flats.	Periodic 300mm
Podocarpus	totara	Totara	Tree	20m	5.00	☀ ⛅	A very attractive specimen tree. Very hardy. The somewhat prickly foliage makes for an effective hedge.	Periodic 100mm
Vitex	lucens	Puriri	Tree	12m	6.00	☀ ⛅	Broad spreading lowland tree with sturdy trunk and branches. Suitable for drier tree pits.	Wet Soil

4.4 OPERATION & MAINTENANCE

Site access is important for the ease of ongoing maintenance of treatment devices. Pre-treatment, such as filter strips, flow diverters, or gross pollutant traps will improve device performance and reduce the maintenance burden. If devices are designed and installed correctly, then maintenance should be minimal and these systems should be largely self-sustaining within the intended design life of the system. a Potential operation and maintenace programme is provided in Table 7.

Often bioretention devices fail due to construction timing or methods. This can be prevented by the following mechanisms:

- Make sure the contributing drainage area has been fully stabilised prior to bringing the practice "on line". Where this is not possible allow for a layer of sand that can be removed following construction and prior to planting.
- Provide for manufactured soils or use appropriate soil testing to ensure soil permeability rates.
- Use the right filter material, which is suitable for filtering stormwater contaminants and for growing plants.
- To avoid floating mulch, use an appropriate wood chip mulch, erosion control fabric, or lay a biodegradable mulch mat.
- Utilise erosion control fabric in high flow areas or slopes until plants establish.
- Off-centre planting to avoid rows leading to preferential flow paths.

The most intensive period of maintenance is during the plant establishment period (first 24 months). Typical maintenance of bioretention devices will include:

- Watering plants until they are established.
- Management of invasive plants by hand removal or cutting and painting.
- Pruning to remove dead or diseased vegetation.
- Pruning to stimulate growth before bud-break in late winter and for flower 'dead-heads'.
- Pest plant monitoring and control.
- Plant replacement or addition.
- Routine inspection to identify sediment deposition, scouring or rilling erosion, impediments to flow (including vegetation) and clogging (evident by 'boggy' soils).
- Removal of sediment where it is smothering plants.
- Repairing any soil damage, replacing plants, and laying erosion control measures where appropriate.
- Tilling or coring soil surfaces if there is evidence of clogging.
- Mulch replenishment until a litter layer is sufficiently developed. Mulch should be placed away from the trunks of trees and shrubs. Grass clippings or animal waste should not be used.

Figure 37:As part of a maintenance programme, make sure planting is not forming an obstruction to stormwater inputs

<table>
<tr><th colspan="14">BIORETENTION DEVICES</th></tr>
<tr><th colspan="14">"SOFT" LANDSCAPE MAINTENANCE SCHEDULE</th></tr>
<tr><th rowspan="3">MAINTENANCE (AS REQUIRED)</th><th colspan="12">GROWING SEASON</th><th rowspan="3">AT COMPLETION</th></tr>
<tr><th colspan="3">SPRING</th><th colspan="3">SUMMER</th><th colspan="3">AUTUMN</th><th colspan="3">WINTER</th></tr>
<tr><th>SEP</th><th>OCT</th><th>NOV</th><th>DEC</th><th>JAN</th><th>FEB</th><th>MAR</th><th>APR</th><th>MAY</th><th>JUN</th><th>JUL</th><th>AUG</th></tr>
<tr><td colspan="14">PLANTS</td></tr>
<tr><td>STAKING</td><td colspan="12">MONTHLY</td><td></td></tr>
<tr><td>TRIMMING AND PRUNING</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>WEED CONTROL</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>WATERING</td><td></td><td></td><td></td><td colspan="4">TWICE WEEKLY</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>REPLACEMENT</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>OVER SOWING</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="14">OTHER</td></tr>
<tr><td>LITTER REMOVAL</td><td colspan="12">MONTHLY</td><td></td></tr>
<tr><td>MULCH REPLENISHMENT</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SEDIMENT REMOVAL</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>CORE OR RAKE SURFACE</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>REPAIR EROSION</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>PONDING/ DRAINAGE</td><td colspan="4"></td><td></td><td></td><td></td><td></td><td></td><td colspan="3"></td><td></td></tr>
<tr><td>PET WASTE REMOVAL</td><td colspan="12">MONTHLY</td><td></td></tr>
</table>

Table 7: Raingarden, tree pit, and planter box operation and maintenance programme

5.0 SWALES AND FILTER STRIPS

Swales are vegetated channels that convey stormwater, slowing the velocity of flows and filtering coarse grained sediments. A filter strip similarly filters stormwater using a planted slope with a dispersed (or laminar) flow.

Both devices are readily applied to primary treatment of stormwater runoff from small sites such as driveways, parking lots, and roadways.

5.1 LANDSCAPE

As for other devices, filter strips and swales can be integrated into existing landscape elements via the following means:

- A legible relationship with natural flow paths and topography.
- Integration with adjacent planting schemes or natural plant communities.
- Wide undulating channels as subtle overland flow paths.
- Unimpeded pedestrian movement and access, including the use of pedestrian boardwalks etc as check dams in swales.
- The use of rock weir structures or logs as check dams in naturalised swales.

Typically swales and filter strips are located along property boundaries or adjacent to impervious areas such as carparks and roadways. Therefore, they frequently define edges to in the landscape (refer figure 39). This can provide for the following functions:

- Separating pedestrians from traffic.
- Glare protection and screening unwanted views.
- Shading impermeable areas using canopy trees as appropriate.
- Provide for a secure edge with spikey, prickly, or sharp leaves.
- Lead the eye along straight axes or continuous curves.
- Soften hardscape areas and reduce carpark and roadway expanses.
- Transition between landscape spaces, land uses, and natural environments.

Figure 38:Diverse swale forms

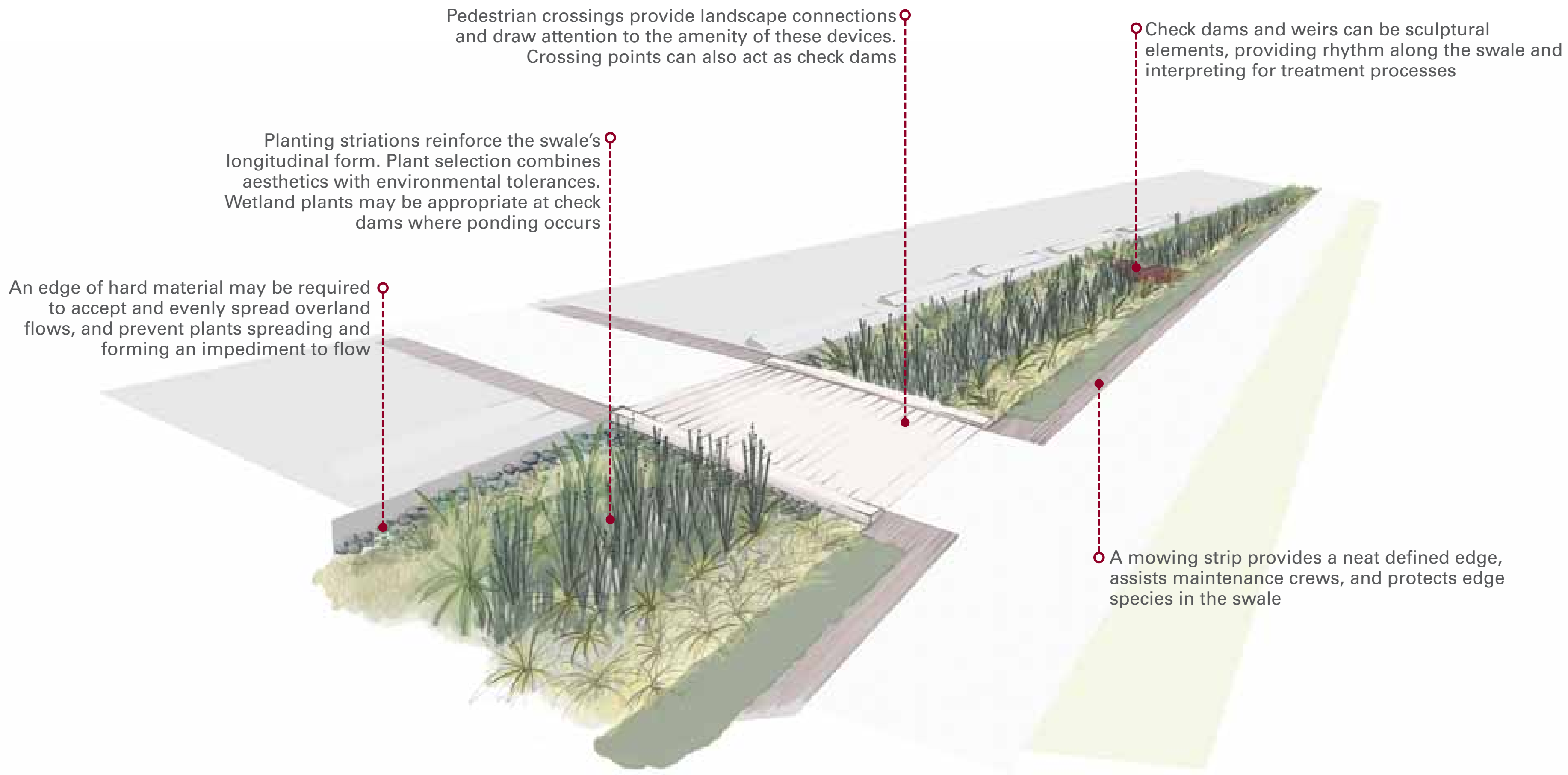


Figure 39: Landscape elements of swale design

5.2 ECOLOGY

Swales and filter strips are extreme environments experiencing both rapid inundation and drought. Plant species are a function of expected flow rates and frequency.

Herpetofauna may not be ideally suited for overland flow paths, but they may thrive under groundcover species on less frequently inundated areas and where higher ground may be reached.

Filter strip devices can provide for important transitional buffers to receiving environments, both in terms of hydrology and for buffering interior habitats (refer figure 41). They can also provide a suite of environmental benefits, common to all devices, for water and air quality, interception of dust, cooling of ambient temperatures etc.

Figure 40: Diverse swale forms leading to exploration

TAXA	DISTRIBUTION	REFUGE	FORAGE
Birds	• Canopy and emergent trees as perches, where possible adjacent and connected to street trees • Attract frugivorous birds with year round fruiting trees	• Canopy and emergent trees for roosting • Mid-canopy trees for nesting • Dense shrub environments on sunny edges for safe refuge	• Year round food supply, including overlap of native tree fruiting • Structural diversity for insectivorous birds • Dense shrub environments on sunny edges provide dense foliage and fruiting • Flowering natives for nectar feeders
Reptiles	• Swales in the middle of streets may be inappropriate for threatened species • Provide for herpetofauna as appropriate, based on the potential to access other remnant habitat areas and the necessity to avoid a genetic bottleneck	• Dense low growing shrub environments on sunny edges • Manuka copses • Dense grasses - flaxes and toetoe	• Habitats that favour insects • Year round low and prostate fruiting shrubs
Invertebrates	• Planted corridors can provide links for non-flying invertebrates to complete their life cycle, especially to stream environments	• Structural plant diversity to optimise ecological niches	• Structural plant diversity to optimise ecological niches • Dense shrub environments • Rock piles and log stacks

Table 8: Swale and filter strip habitat enhancement

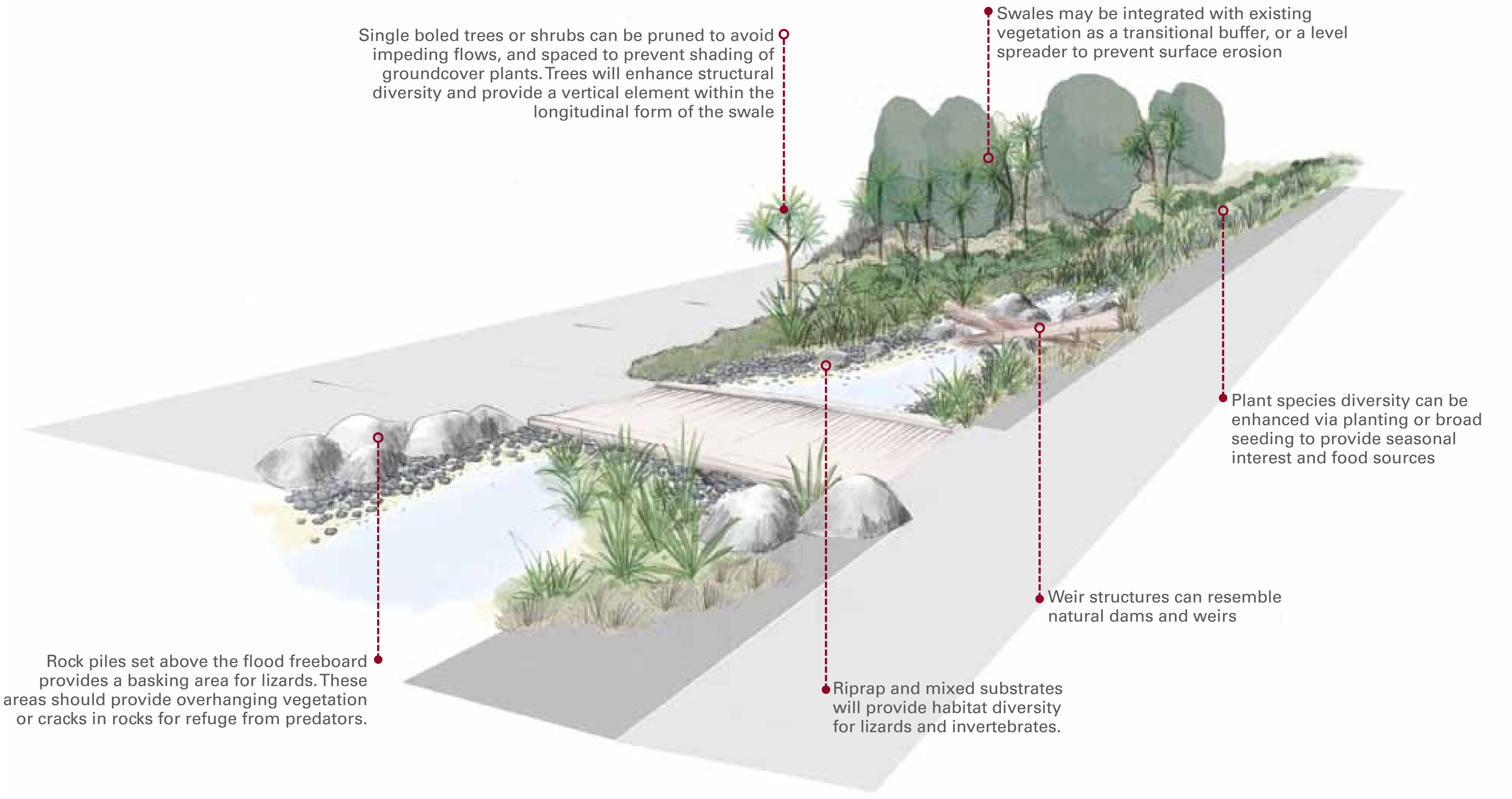


Figure 41: Design elements to provide for a naturalised overland flow path and to optimise ecological benefits

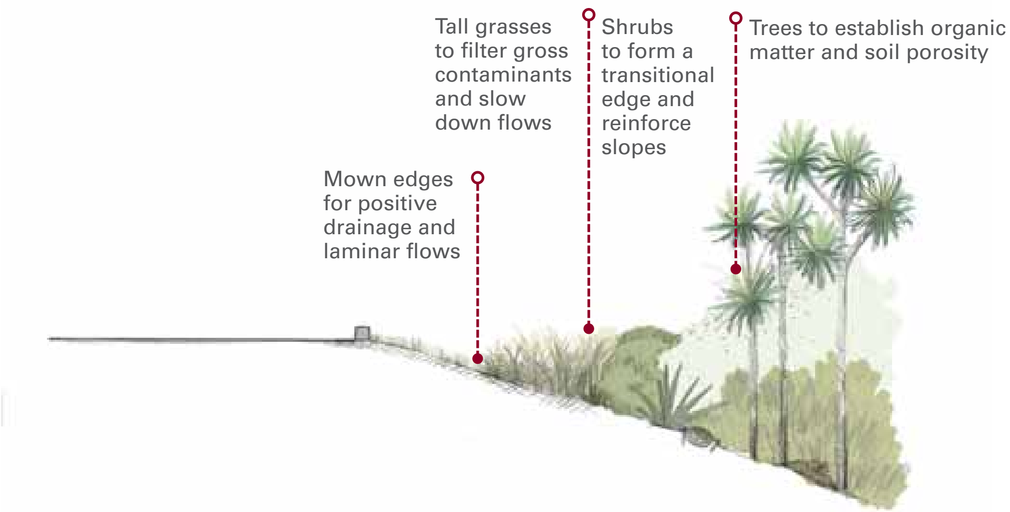
5.3 PLANTING

Planting within a swale is primarily a function of water conveyance, water quality treatment, and inundation levels in the following ways (refer figure 42):

- The lowest point of the channel will require plants that can be inundated on a periodic basis and will flatten or part under flows to reduce drag. These plants will also require large surface root systems or rhizomous connections to form a dense mat and prevent preferential flow paths and channel erosion.
- Plants on the side of the channel will require the tensile strength to retain soils during high flow events.
- Plants at the upper channel will require tolerance of long periods of drought, with periodic inundation.
- Edge plants will require tolerance to climatic extremes, maintenance and potentially wilful damage.

The establishment of vegetation is an important aspect to ensure the effective performance of swales and filter strips. Once planted, monitoring should occur to ensure a thick even spread of vegetation. Where hydraulics are especially important, uniform low-mow grass species may be the most appropriate planting approach (kept to 100–200 mm in height). However densely planted vegetation higher than 200mm provides for greater sediment retention and may still accommodate sufficient flows by increasing the cross-sectional area of the swale.

Depending on species and stormwater flow rates, trees should generally be planted to the side of the channel to prevent impediment to flow and to avoid regular inundation. Trees should ideally be flexible, single-bole trunks with upright growth forms and wispy foliage to avoid shading groundcover plants.



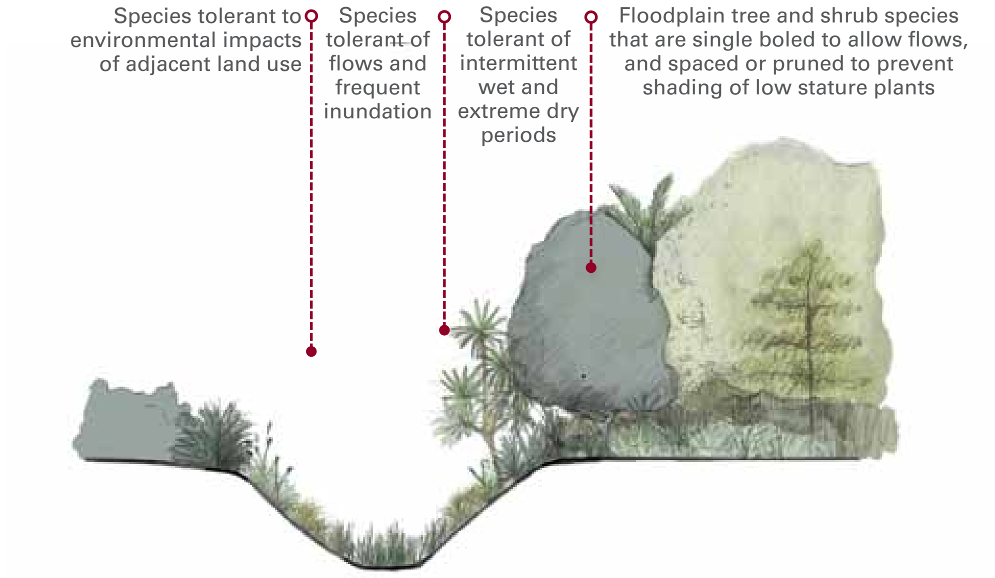


Figure 42: Planting sections for swales and filterstrips

GENUS	SPECIES	COMMON NAME	DESCRIPTION	HEIGHT (M)	SPREAD (M)	WATER TOLERANCE	SUN / SHADE	NOTES
Acaena	anserinifolia	Hutiwai	Ground Cover	0.15	1.0			Very dense, fast-growing plant. Good for suppressing weeds and preventing surface soil erosion. Velcro-like seeds.
Apodasmia	similis	Oioi, Jointed rush	Sedge & Rush-like	1.5	1.0			Elegant 1.5m. Ideal garden plant, very hardy and slow creeping. Swale plant ideal to filter sediments and minimise erosion..
Astelia	grandis	Swamp astelia	Lily & Iris-like	2	2.0			Olive green flax-like leaves. Large 2m clumps, prefers swamps up to 50cm deep but grows in drier gardens.
Baumea	articulata	Jointed twig-rush	Sedge & Rush-like	1.8	2.0			Sturdy upright bright green stems, will tolerate both drier soil & deep water. Graceful 2m, brown seed heads in summer .
Baumea	complanata	Shiny sedge	Sedge & Rush-like	0.7	1.0			Flattened bright green foliage. Forms very attractive clumps. Extremely rare in the wild - now only in three locations in Northland.
Baumea	juncea	Blue coastal sedge	Sedge & Rush-like	1.0	1.5			Slender blue-green rush-like foliage. Creeping habit will tolerate both dry and water- logged soils.
Baumea	tenax	Bumblebee nut sedge	Sedge & Rush-like	1.0	1.5			Rigid dark green foliage. Slow spreading to form tufts even in swales of low fertility.
Blechnum	novae-zelandiae	Kiokio	Fern	1.0	2.0			A very hardy fern forming a tidy border along the edge of swales. New fronds pink in the sun.
Carex	dipsacea		Sedge & Rush-like	0.75	0.75			Light green tussocks with tufted habit. Damp areas.
Carex	flagellifera		Sedge & Rush-like	0.75	0.75			Tussock grass with fine green foliage. Versatile sedge which grows in sun and shade, moist and dry.
Carex	gaudichaudiana		Sedge & Rush-like	0.4	1.0			A highly variable species with a densely tufted, creeping rhizome. Requires moist, open situation. Forms thick swards.
Carex	geminata		Sedge & Rush-like	1.0	2.0			Bright green tussocks with a creeping rhizome. Similar to C.lessoniana.
Carex	lessoniana	Spreading swamp sedge	Sedge & Rush-like	1.0	2.0			Green tussocks with a wide-creeping rhizome. Damp or swampy ground. Ideal plant for stabilising stream banks and swales..
Carex	ochrosaccus		Sedge & Rush-like	0.75	0.75			Forms light green, robust tufts. Quick to establish. Often grows on stream banks.
Carex	pumila	Blue dune sedge	Sedge & Rush-like	0.3	2.0			Vigorous rhizome spreading sand sedge. Suits sunny well drained sites where it will spread rapidly.
Carex	secta	Purei, makura	Sedge & Rush-like	1.5	2.0			Green swamp tussock. Can form a mop of foliage above a 1m trunk. Prefers damp sun but also tolerates dry shade.
Carex	solandri		Sedge & Rush-like	0.6	0.6			Frequently growing in open damp sites it will tolerate dry forest conditions. Useful for planting swales although not rhizomatous.
Carex	virgata		Sedge & Rush-like	1.0	0.8			Vigorous clumping fine-leaved, sharp edged, bright green tussock. A successful coloniser in dry and damp areas.

Table 9: Swale and filter strip plant schedule

GENUS	SPECIES	COMMON NAME	DESCRIPTION	HEIGHT (M)	SPREAD (M)	WATER TOLERANCE	SUN / SHADE	NOTES
Carpodetus	serratus	Putaputaweta	Tree	5.0	3.0			Attractive tree. Can be covered in small white flowers (summer). Prefers damp soils, sun or shade.
Coprosma	arborea	Mamangi	Tree	6.0	5.0			The largest Coprosma can form a moderate size tree. It is best in drier conditions but will tolerate short-term flooding.
Coprosma	propinqua	Mingimingi	Shrub	3.0	2.0			Divaricating shrub with a range of forms, but all small-leaved. The female has blue fruit. Frequently a swamp dweller.
Coprosma	robusta	Karamu	Shrub	5.0	3.0			Fast growing shrub ideal for rapid establishment in swales. Birds enjoy the masses of orange fruit on female plants.
Coprosma	tenuicaulis	Hukihuki	Shrub	2.0	1.0			Small-leaved compact swamp shrub. Fine grey foliage and black fruit. Excellent in damp conditions.
Cordyline	australis	Cabbage tree	Tree	8.0	3.0			A classic New Zealand icon with single stem and round head. Clusters of scented flowers (spring). Best planted in the middle of the swale to limit spread of old leaves.
Cortaderia	fulvida	Toetoe	Grass	1.5	2.0			Smallest of the Cortaderia's. 2m tall drooping flower spike (spring/ summer). Ideal as shelter or feature plant.
Cyperus	ustulatus	Giant umbrella sedge	Sedge & Rush-like	1.5	2.0			Sharp-edged swamp grass. Fast growing with olive-green leaves. Ideal for wetland revegetation.
Dianella	haematica	Turutu	Lily & Iris-like	0.5	1.0			Slender flax-like leaves. Beautiful blue-purple berries (summer-autumn). This is a wetland form of Dianella nigra.
Dicksonia	squarrosa	Wheki	Tree Fern	5.0	2.5			Wheki tree fern. Can form multiple slender stems. Prefers a little shelter. Fast growing.
Doodia	squarrosa		Fern	0.3	0.4			Hardy fern with pink new fronds. Occurs in moist areas as well as dry.
Eleocharis	acuta		Sedge & Rush-like	1.0	1.0			A wiry erect sedge with tufted rhizome. Culms normally 20cm but can grow up to 1m . Ideal for edge of swale where it can be mowed.
Ficinia	nodosa	Knobby club-rush, Wiwi	Sedge & Rush-like	1.0	2.0			A fine bright green clump forming reed that thrives in dry rocky situations but will tolerate wet conditions as well..
Gahnia	xanthocarpa	Tupari maunga	Sedge & Rush-like	3.0	3.0			Forms a large dark green clump with cutting foliage. Drooping flower spikes to over 3m. Prefers moist conditions.
Gunnera	dentata		Ground Cover	0.05	1.0			Green creeping foliage with orange berries in summer. Requires damp areas and will spread amongst other plants.
Gunnera	monoica		Ground Cover	0.01	1.0			A robust groundcover Gunnera that prefers shaded moist conditions. Will spread amongst other taller plants.
Histiopteris	incisa	Water fern	Fern	1.0	2.0			Bracken-like in habit with soft glaucous fronds which renew each spring. Prefers open areas, swamps and streams.
Hoheria	populnea	Houhere, Lacebark	Tree	6.0	3.0			A fast growing, graceful tree. Abundant scented flowers.

GENUS	SPECIES	COMMON NAME	DESCRIPTION	HEIGHT (M)	SPREAD (M)	WATER TOLERANCE	SUN / SHADE	NOTES
Isolepis	prolifer	Prolific rush	Sedge & Rush-like	0.3	2.0			'Light bright green fleshy sedge. Fast-spreading and prolific particularly suited for wetland areas.
Juncus	edgariae	Wiwi	Sedge & Rush-like	1.5	1.0			Forms tight clumps from wiry stems. Tolerates extremes of wet and dry for short periods. Was known as Juncus gregiflorus.
Juncus	pallidus	Giant rush, Wiwi	Sedge & Rush-like	1.7	2.0			Forms light green robust clumps. Creeping rhizome. Colonises readily from seed.
Juncus	sarophorus	Wiwi	Sedge & Rush-like	1.5	1.0			A vigorous species that will tolerate drier conditions and can be found in pasture.
Lepidosperma	australe	Square-stemmed sedge	Sedge & Rush-like	1.0	1.0			Bluish grey foliage on a slow creeping rhizome forms dense clumps on poor gumland soils.
Leptinella	dioica	Shore leptinella	Ground Cover	0.10	1.0			Fast growing. Small bright green fern-like leaf. Coastal.
Leptospermum	scoparium	Manuka	Tree	4.0	2.0			Abundant white flowers (spring). Very hardy. Sunny position, most soils. Source a local form that tolerates flooding.
Machaerina	sinclairii	Tuhara, Pepepe	Sedge & Rush-like	1.0	1.5			Bright green iris-like leaves. Tall flowering spike with graceful bronze seed head (summer).
Microlaena	stipoides	Rice grass	Grass	0.3	1.0			Vigorous gowth for dry edge of swale.. Turf forming. Excellent for lawn, under trees, coastal bank or cliff sites.
Phormium	tenax	Harakeke	Flax	3.0	3.0			Tolerates wet and/or coastal conditions. Plant away from edge of lawn to avoid entangling the mower.
Sophora	microphylla	Small-leaved kowhai	Tree	6.0	4.0			Tangled zigzag juvenile stage taking up to 10yrs to flower. Eventually becoming a tall upright tree.

5.4 OPERATION & MAINTENANCE

Swale and filter strip treatment performance is tied to vegetation establishment. During construction, it may be necessary to divert flows around treatment devices until the vegetation has become established, or alternatively utilise mulch mats, pegs, and erosion control fabrics to protect plants and retain soils. If preferential flow paths occur prior to plant establishment this can be remedied by setting in branches (singularly or in tied bundles) perpendicular to flows to capture sediment and act as a level spreader.

The most intensive period of maintenance is during plant establishment (first two years) when weed removal and replanting may be required. It is also the time when large loads of sediments can impact on plant growth. In general, the operation and maintenance of swales and filter strips are primarily concerned with removal of litter etc, rectification of erosion, care for planting and the operation of check dams (refer Table 10).

Figure 43: Diverse swale forms in open space areas as overland flow paths

SWALE & FILTER STRIP

"SOFT" LANDSCAPE MAINTENANCE SCHEDULE

MAINTENANCE (AS REQUIRED)	GROWING SEASON												AT COMPLETION
	SPRING			SUMMER			AUTUMN			WINTER			
	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	
PLANTS													
STAKING	MONTHLY												
TRIMMING AND PRUNING				■						■			
WEED CONTROL	■			■			■			■			
WATERING				TWICE WEEKLY	■	■	■						
REPLACEMENT	■									■	■	■	
OVER SOWING	■						■						
GRASS AREAS													
MOWING	TWICE MONTHLY			MONTHLY			MONTHLY			MONTHLY			
FERTILISER	■						■						
WEED CONTROL	■			■		■			■				
MULCH REPLENISHMENT	■						■						
OTHER													
LITTER REMOVAL	MONTHLY												
SEDIMENT REMOVAL				■									
REPAIR EROSION & LEVELS	■									■			
REPAIR OF EDGES	■			■			■			■			
REPAIR OF BARRIERS	■			■			■			■			
PET WASTE REMOVAL	MONTHLY												

Table 10: Swale and filter strip operation and maintenance programme

6.0 STORMWATER WETLANDS & WETLAND-PONDS

Constructed stormwater wetlands are systems built to mimic the water cleansing processes of natural wetlands. Wetland environments represent the intersection of aquatic and terrestrial ecologies and support a wide variety of vegetation types. In this way, they can be designed as a landscape feature of significant amenity, with diverse habitat types, and opportunities for passive recreation.

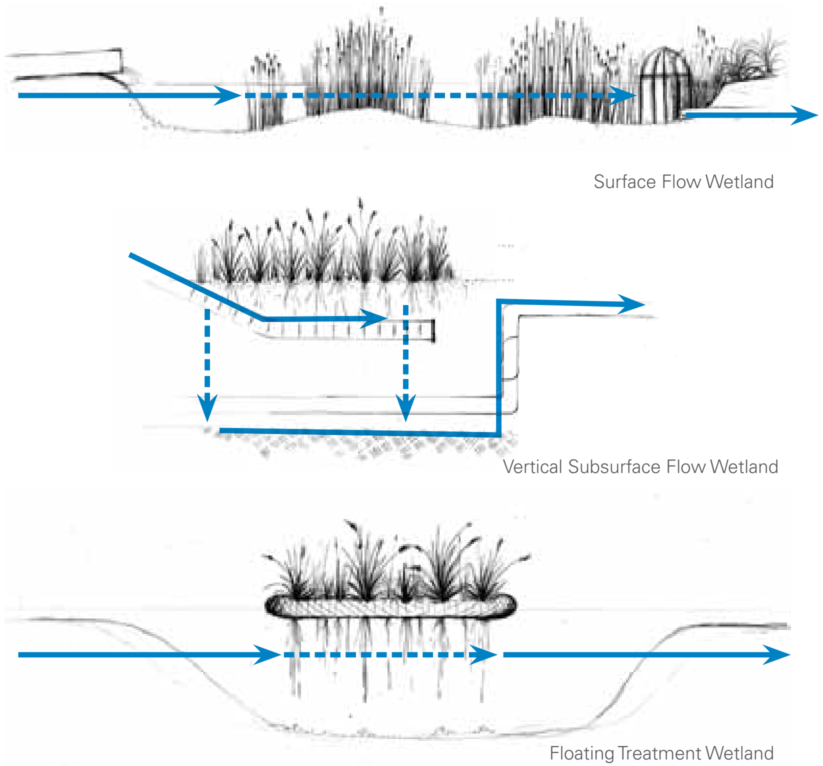


Figure 44: Three main types of constructed stormwater wetlands

There are three main types of constructed wetland: surface-flow wetlands, sub-surface wetlands, and floating wetlands (refer figure 44). A surface-flow (SF) wetland consists of a basin of varying water depths with soil or other media to support wetland vegetation and a water control structure that maintains water depth above the substrate. Water is treated as it flows across alternating zones of deep water pools and shelves of wetland plants.

A subsurface flow (SSF) wetland is constructed of a sealed basin filled with a porous media. Stormwater is treated as it passes through the media and rootzones of wetland plants. Stormwater remains below the surface of the substrate at all times. SSF wetlands are best suited to water inputs with relatively low solid concentrations to prevent clogging, and relatively uniform flow conditions to ensure plant survival (Davis 1995).

A floating treatment (FT) wetland is a raft that supports wetland plants, growing in a hydroponic manner, within a deep water basin (Headley & Tanner 2006). FT wetlands are still a relatively unproven technology in stormwater ponds but laboratory testing has revealed there is significant potential for these systems for the filtering of fine sediments or contaminants in solution. They are also likely to be highly effective for shading open water areas, and as a curtain to trap heavier sediment, specifically at the exit of forebays.

6.1 LANDSCAPE

Wetlands and ponds are unusually rich environments formed by interweaving elements, diverse plants communities, and sweeping landforms.

Landscape Context

The impacts of stormwater wetland construction can be reduced by designing within existing landforms, hydrological systems, and vegetation associations. Designs that are integrated with existing conditions in this way will emphasise the existing natural character values of a site, and are more likely to achieve a 'sense of permanence' once established. This can be reinforced by incorporating existing elements such as specimen trees, rock outcrops, crags (dead trees), and wetland springs to reference the sense of place and add visual diversity. Wetlands sited close to existing natural areas, especially riparian environments, provide for complementary habitats to enhance biodiversity and natural character values.

Landscape Amenity

If sited within accessible open space, constructed wetlands or ponds can significantly enhance the built environment and provide a suite of environmental services (e.g. interception of dust, moderation of heat, noise, and light). Wetland environments provide a refuge for local residents and a place of tranquillity. Elements of water and associated lush native vegetation adds significantly to the amenity of a development (refer figure 46).

Planting design is an important consideration for both wetland function and amenity values. Plants can be laid out in drift forms to mimic successional habitats, structured to frame selected views, and vary in height and composition to enrich the spatial experience from paths and boardwalks. Densely planted vegetation provides refuge for animals, or may prevent access of people to deep open water or sensitive wetland environments.

Vegetation in adjacent open space and streetscape areas can be integrated into wetland and pond environments, act as a buffer, or extend habitat opportunities.

Where structures are required as part of the wetland's function, there may be opportunities to utilise biotechnical approaches (a combination of plants and structures) to ensure a consistent natural quality for the wetland. For example, planted geotextiles may be used for erosion control, and planting within the top layers of gabion cages can form the edge of forebays (refer figure 47).

Landscape Recreation

Ponds and wetlands provide a destination for passive recreation, with potential viewing areas, pathways, and gathering spaces. Community education is also possible with appropriate information or public art. Constructed wetlands are optimal areas for education as they can demonstrate basic principles of plant succession, food webs, and nutrient cycling. These environments are striking settings for artwork with diverse environments and strong elemental references (refer figure 48).

Connections and spaces around ponds and wetlands may be formed by a combination of plants, landform, and structure. Landforms can vary to provide diverse views and senses of enclosure. Plants can form open sedgelands, dense flaxlands, and cool and dark forests, providing for diverse and changing experiences within the wetland. Weirs and maintenance access can coincide with pedestrian paths and boardwalks, where they do not impede flood flows.

Figure 45: Diverse plant communities enhance natural character values and visual interest in stormwater wetlands

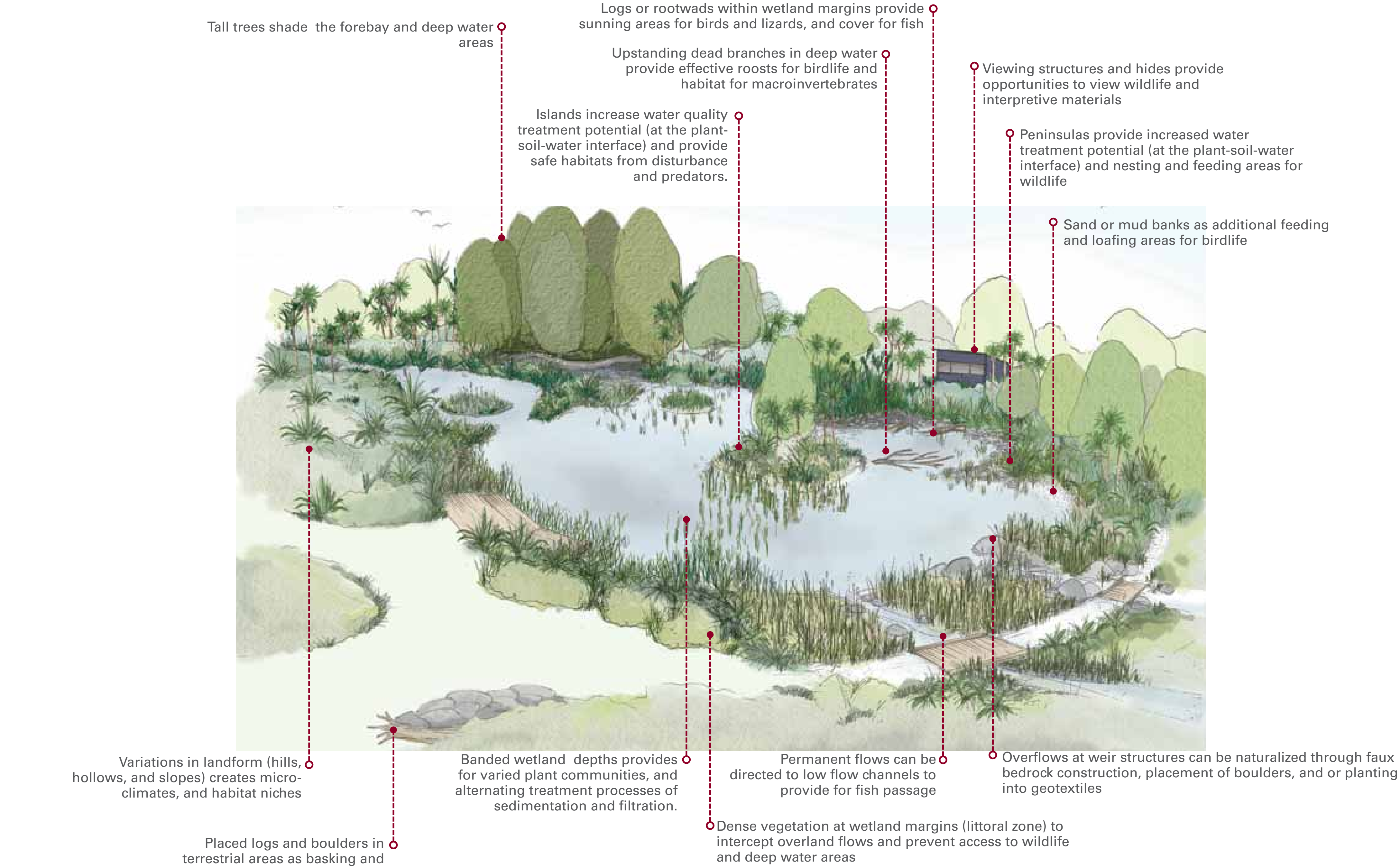


Figure 46: Stormwater wetland ponds as a natural feature of the landscape

Wetland environments increase their value to a community and to urban habitat when they are part of a connected greenway or open space network. Where wetlands are adjacent to other recreational areas, or riparian environments, they can be designed as part of a connected system, offering a particular experience, level of inter-activity, or representational planting community. Other means to optimise the landscape experience of a wetland includes:

- Panoramic views and concealed vantage points, leading to a sense of discovery.
- Choices of pathways, which also responds to crime prevention issues.
- Space and corridor formation through landform and planting variants.
- Gathering places and seating in reflective spaces and vantage points.
- A variety of water dynamics - still and reflective, rushing or dropping etc.
- Walking across environmental gradients such as successional vegetation or varying wetland plant communities.
- Viewing wetland structures as sculpture - emphasising their function (at outlets, weirs etc).
- Bridges, piers, platforms, or hides to engage safely with water and wildlife.
- Clearly defined accessways to encourage walking while protecting sensitive areas.
- Interpretive signage to educate and encourage appropriate behaviours such as not feeding birds and keeping dogs on leashes.

Stormwater treatment devices do not necessarily need to replicate nature or natural landscape, but rather should be developed with a respect for natural ecosystems and processes, which may find expression in a variety of design solutions (Schaffer & Barnsley 1998).

Where wetlands are not associated with an adjacent natural systems or are bordered by urban environments, their shape and planting design may be architectural, to reveal wetland processes in simplified but strongly contrasting forms. These wetlands provide a different quality of space, but one that is no less approachable for exploration (refer figure 49).

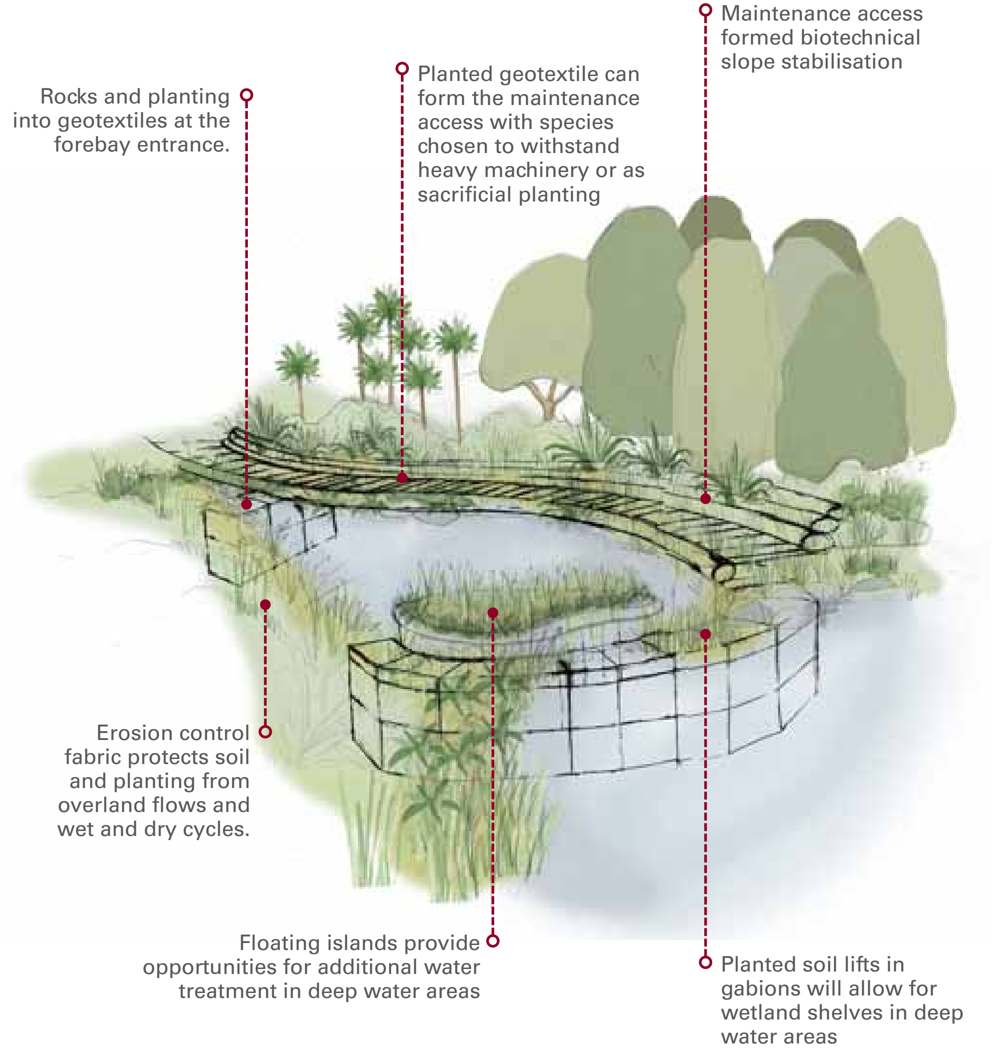


Figure 47: A biotechnical response to forebay construction achieves structural integrity as well as a natural landscape

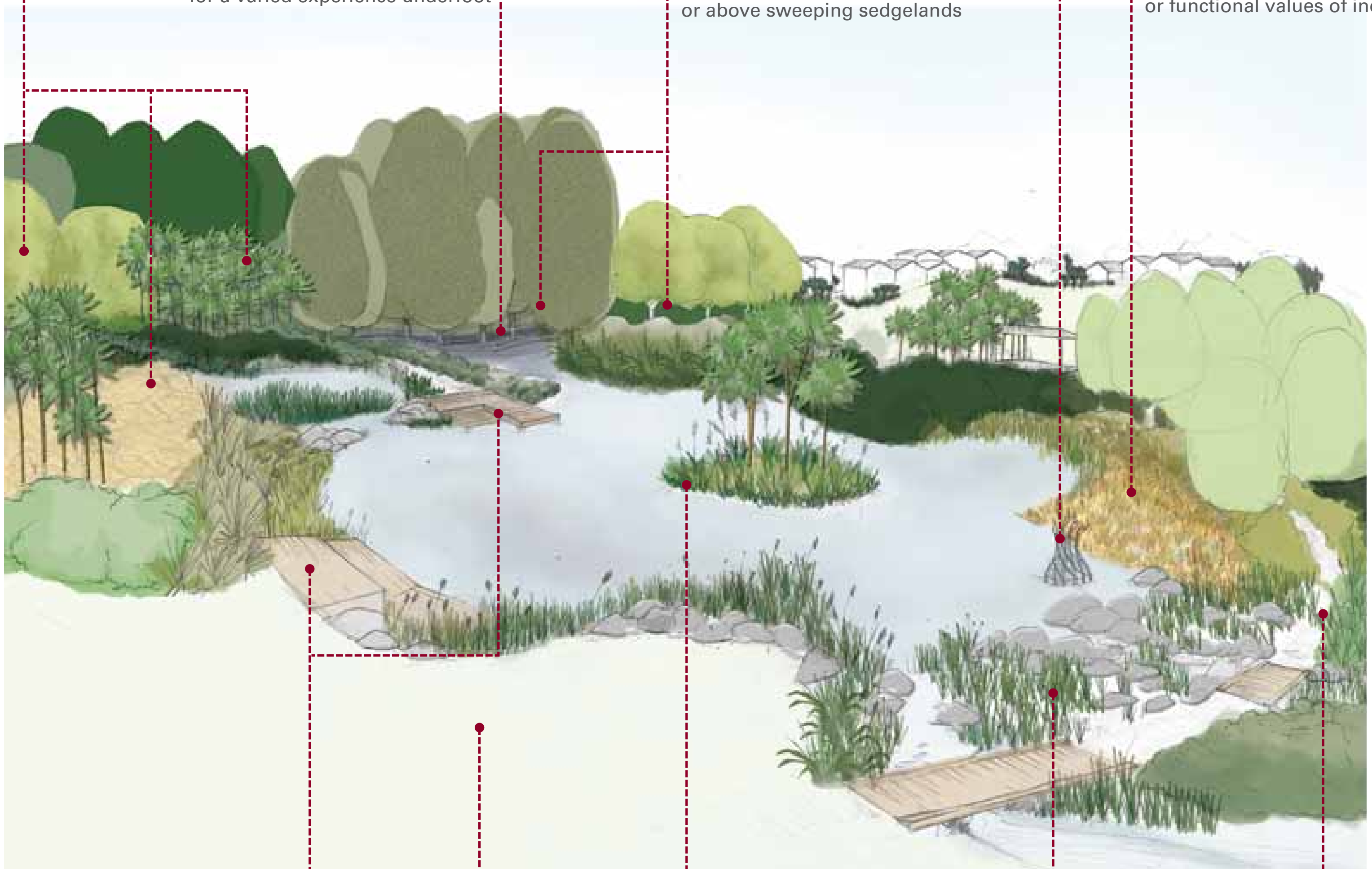


Figure 48: Stormwater wetland ponds for passive recreation

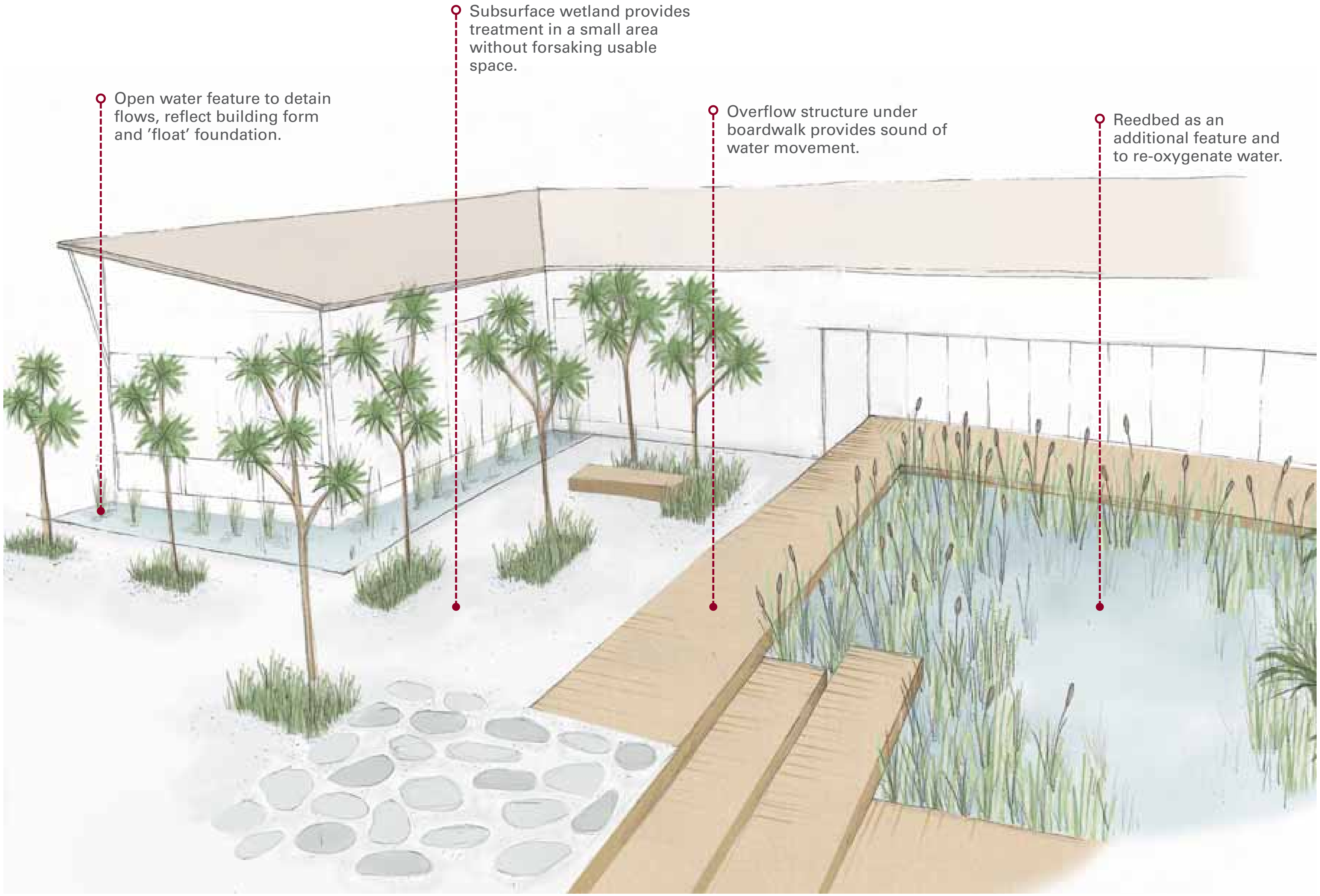


Figure 49:Treatment wetlands that contribute to adjacent architecture

6.2 ECOLOGY

The key factors that influence ecology values for ponds and small wetlands are water quality, proximity to other wetland habitats, vegetation species and structure, and physical structure (Williams et al. 1999).

Ecological Form and Structure

Biodiversity is optimised in a wetland through physical heterogeneity. This is a function of diverse environmental gradients from aquatic to terrestrial, and from edge to interior habitats. In designing a constructed wetland to attract a variety of wildlife, it is desirable to incorporate as much physical change in terms of water depths, landform, substrates, and plant communities.

The biodiversity values of wetland and pond margins may be enhanced by providing fallen logs, boulder outcrops, and alternating dense vegetation, gravel beaches, and hard edges. Where possible, a variety of substrates (eg sand, pebbles, clay) can be used to promote diversity along the shoreline with specialised niches for plants, aquatic macro-invertebrates and other animals. Wetland design should ideally provide an irregularly shaped shoreline to maximise the length and variety of edge habitat. However, it is important to avoid the creation of small isolated ponds which might provide breeding habitat for mosquitoes (Winning & Beharrell 1998).

As a rule, 25–50 % of the water surface area in a treatment pond should be shallow enough to support wetland plant establishment, and 50 – 75% of the water surface should be greater than 1 metre in depth to stabilise water temperatures. These variable depths provide an effective ratio of planted to open water which increases bird diversity. If possible a refuge pool (a deep area in the main pond) can be formed to support fish and aquatic insects on the occasions that the pond is drained for maintenance (Martin et al 2008).

Figure 50: Opportunities for outdoor classrooms, information, and interpretation in wetland environments

Gentle slopes provide habitat for larger wading birds, and, when the water level drops, expose mudflats which are feeding habitat for smaller wading birds. Mudflats and sandbars are important feeding habitat for wading birds such as pied stilt. These feeding areas can occur as shallow shelves, island edges, and peninsulas along the shoreline. Rich foraging areas for birds also occurs at the entry point of streams to online ponds, where oxygen rich riffle environments increase the diversity of fish and invertebrates.

Wetland ponds greater than half a hectare will benefit from the inclusion of an island. This will increase margin habitat for plants, fish, and aquatic insects, as well as providing roosting and nesting refugia for birds away from disturbance by humans and dogs. Floating wetlands provide similar habitat to fixed islands, with the added value of a suspended root zones, where fish can shelter and forage.

Debris such as rocks, tree limbs and hollow logs can be placed in and around the wetland and on islands. Large logs and tree limbs placed in relatively deep water, with portions above the water level, will provide secure low-level roosts for water birds, and over time will gradually break down providing food as well as habitat for a range of fish and aquatic invertebrates (Martin et al. 2008). Rock material used for erosion protection can also provide habitat for macro-invertebrates, fish and reptiles (when placed on the landward side of the wetland).

Individual tall trees close to ponds should be left if they do not cause instability of pond embankments when they die. These trees provide roosting and nesting sites for herons, New Zealand kingfisher, and shags. However, large trees are rarely present at a newly constructed sites so an alternative is to provide nesting boxes (for the likes of shags and kingfisher) for roosting and nesting.

Ecological Connections

Wetlands with connections to existing riparian environments offer excellent opportunities to provide fish passage to increased habitat areas. It is important to provide unimpeded access to stormwater treatment devices where they are offline (upstream of the receiving environment), and critical where wetland ponds are on-line (constructed in-stream). Refer to TP131 and TR2009/084 for ARC's Fish Passage Guidelines. The general requirements for enabling fish passage are ensuring constant, low velocity water flow of adequate depth, without steep weirs or hanging falls, and with resting pools (ARC 2008). The creation of riffle areas not only allows for native fish migration, but also deters mosquitoes from breeding.

The proximity of riparian areas (and their connected systems) will also aid the dispersal of birds, invertebrates and herpetofauna, to spread their home range, to complete their life cycle, and to disperse individuals, populations, and genetic material.

Wetland environments also benefit from the adjacent terrestrial vegetation, to increase the diversity of edge habitats, and buffer the wetland environments from overland flows, invasive species, and environmental extremes.

Figure 51: Water fowl are welcome visitors, but may have a negative impact on water quality in stormwater wetlands

Plant diversity

Plants are the most important habitat enrichment feature of a wetland environment, as they underpin the food web and provide shelter and breeding sites for a range of birds, fish and insects (ARC 2008). Gentle slopes (about 10% slope) from the wetland shoreline will provide a gradual change in water depth and thereby encourage the development of planting zones. Landform variety, (steep banks, hollows, and hills) will also add opportunities for plant species diversity. Within a wetland the composition of plants can provide for representative plant assemblages as they would occur naturally and thereby increasing the likelihood of attracting species specific to these environments (e.g. fernbird in gumland environments, cryptic marshbirds in reedlands).

Shrub planting can provide significant opportunities for forage and refuge for birds and herpetofauna along wetland banks, and provide a dense transitional edge at the boundary of wetland environments to prevent edge-effects disturbance. Tall trees can be incorporated for shading of open water areas, diversity of canopy layers to optimise habitat niches, and provide roost areas for birds. Forest types specific to wetland areas which are frequently rare or under-represented in the ecological district can also be considered e.g. kahikatea or swamp maire forest.

When planning the composition of planting species, it is important to consider the seasonality of the food source provided (nectar, flowers and berries, as well as insects that associate with plants).

Figure 52: Islands, crags, and fallen logs offer unique habitat opportunities in wetland and pond environments

Fauna opportunities

Pond-wetland complexes that provide a range of feeding, nesting, brood rearing, loafing and resting sites represent greater opportunities for birds within their life cycle requirements. Features that will attract a wider range of water-birds include (Tanner & Kloosterman 1997):

1. A variety of feeding areas – based on feeding methods and morphological adaptions (eg. bill shape) enable individual species to exploit ecological niches. A mosaic of openwater and vegetated zones generally provides the greatest diversity of habitats. Gently sloping edges of ponds and wetlands are generally the most productive and can be lengthened by creating irregular margins and embayments.
2. Vegetative cover – many species favour sites where overhead and ground cover provide security and shelter. Ground nesting waterfowl require cover to conceal their nests, and to enable broods, fledglings, and moulting adults to evade aerial and ground predators. Aquatic and terrestrial vegetation also provides an important source of food, both directly in the form of shoots, leaves, berries and seeds, and indirectly as habitat for invertebrates.
3. Loafing areas – clear areas of water edge which can be accessed by swimming and walking from the water are generally favoured.
4. Reduced predation – the greatest threat to wetland birds (next to habitat loss and for gamebirds recreational hunting) is predation. Wild cats, mustelids, possums and rats all impact on small wetland bird species and kill nestlings and young ducklings. Approaches to reduce the threat posed by predators include direct control by trapping and poisoning, and provision of secure nesting sites such as nesting boxes, islands, and floating platforms.
5. Linkage to wider networks of natural wetland and riparian habitat – siting of pond-wetland systems near natural wetlands and riparian corridors enables fauna to utilise a range of different wetland areas.

Opportunities exist to create habitat for skinks by planting species that provide optimal habitat structure i.e. dense, low growing vegetation. Skinks also apreciate a range of conditions from shady to dry and sunny. Habitat potential can be enhanced by placing logs (or wooden disks) amongst vegetation and along pathways to provide skink refugia, or placing rock mounds for basking next to dense grass and shrub areas. The habitat requirements of Geckos should also be considered if there is an existing population known to occur nearby in adjacent terrestrial vegetation.

It is important to achieve a balance through the competing requirements of different species utilising wetlands and ponds. For instance, waterfowl prefer open edges for loafing, however large numbers of these birds can result in increased faecal material in and around the wetland or pond. An American Falls Sub-basin Assessment estimated that an average Canada goose contributed 1.57 grams of nitrogen and 0.49 grams of phosphorus per day (Easton and Shaver 2009). A potential solution to this is to densely plant or place rocks along wetland margins to reduce loafing areas, and plant tall vegetation to limit 'flight lines'.

Managing pests is an integral part of managing biodiversity. As such, methods to control mammalian, avian, invertebrate and plant pests are outlined in the specification section of this document.

Figure 53: Potential to construct temporary fish refugia until plants can establish and maintain overhanging structures

TAXA	DISTRIBUTION	REFUGE	FORAGE
Bush Birds	• Canopy and emergent trees as perches, where possible adjacent and connected to street trees • Attract frugivorous birds with year round fruiting trees	• Canopy and emergent trees for roosting • Mid-canopy trees for nesting • Dense shrub environments on sunny edges for safe refuge • Consider roost and nest boxes	• Year round food supply, including overlap of native tree fruiting Structural diversity of forest areas for insectivorous birds • Dense shrub environments on sunny edges provide dense foliage and fruiting • Flowering natives for nectar feeders • Consider nectar-feeding stations with species specific access
Water Birds	• Clear flyways in line with grass loafing areas • Large bodies of water	• Dense sedge and rushland fields for marshbirds • Islands • Open views from loafing areas • Uninterrupted open water	• Adjacent grass loafing areas • Peninsulas, sand banks and mudbanks for stilts and herons
Reptiles	• Provide for herpetofauna as appropriate, based on the potential to access other remnant habitat areas and the necessity to avoid a genetic bottleneck • Corridors can be as simple as a hedgerow or line of plants • Consider wooden disks placed in tall grass and shrublands for refuge and landscape connections	• Rock piles and log stacks Dense low growing shrub environments on sunny edges • Kanuka and manuka copses • Dense grasses - flaxes and toetoe • Developed leaf litter under canopy	• Habitats that favour insects (see below) • Year round low and prostate fruiting shrubs
Invertebrates	• Planted corridors can provide links for non-flying invertebrates to complete their life cycle, especially to stream environments	• Rock piles and log stacks • Structural diversity of forest areas to optimise ecological niches and leading to dense and diverse leaf litter • Consider weta boxes	• Structural diversity of forest areas to optimise ecological niches and leading to dense and diverse leaf litter • Rock piles and log stacks
Fish	• Avoidance for perching culverts, rising manholes, and pipes within flows to provide access between receiving environments and off-line ponds • Minimise drop structures greater than 100mm or provide for wetted surfaces over any falls • Provision of resting areas above and below drop structures • Consider directing low flows through a channel rather than pipe for fish passage	• Wetland tree species for shade and refuge in root systems • Edge planting of overhanging grasses etc • Potential to insert tree root wads and branches to provide overhangs • Diverse substrates for both interstital spaces and mud bottomed refugia • Deep water pools • Floating islands provide refuge between root systems	• Wetland tree species for falling insects and detritus • Edge planting of overhanging grasses for falling insects • Substrates and cool temperatures that provide for increased diversity and biomass of freshwater invertebrates

Table 11: Wetland and wetland-pond habitat enhancement

6.3 PLANTING

Hydrophilic (water-loving) plants are an important component in constructed wetlands (Sainty & Beharrell 1998), with their roles including:

- Aiding in the reduction of nutrient and heavy metal concentrations.
- Influencing sediment deposition and filtering sediment particles from the water column.
- Influencing hydrology and hydraulics in constructed wetlands by promoting even flows.
- Providing shade and decreased light to limit algae and reduce water temperatures.
- Decreasing erosion by reducing wave energy and flow velocities while binding soil particles with root systems.
- Providing a basis for wetland food chains and supplying shelter for invertebrates, reptiles and birds.
- Improving visual amenity, as discussed in the previous landscape section.

Planting for constructed wetlands systems primarily consists of three main vegetation types (refer figure 55):

Emergent zone planting (from 1.0m to 0.2m below design water level) – to assist in water quality improvement through filtration and absorption, and bed protection through reduction of scouring (Wiese, Raft & White 1998). The most effective way to meet the stormwater quality objectives is to form bands of planting perpendicular to flow that respond to designed depths. Single species bands of planting are not misplaced, since these may occur in natural wetland systems. Emergent wetland vegetation provides forage and refuge above and below the water line, and diverse microbial assemblages where aerobic environments at the root zones meet anaerobic areas within the sediment.

Littoral zone vegetation (greater than 0.2m below design water level). The vegetation at the wetted edge protects batter slopes from erosion (from flooding or continuous wet and dry cycles). The littoral zone also intercepts gross sediments from entering the wetland via overland flow and provides treatment of nitrogen and metals in the root zone entering via influent groundwater.

Figure 54: Wetland walks provide diverse spatial experiences and dynamic changes to plants and water

Terrestrial zone (including existing vegetation) Terrestrial vegetation includes areas that expect to be inundated from the wetland on rare flood events and therefore comprise a wide variety of floodplain, escarpment, or upland vegetation types. This vegetation buffers the wetland environment from physical and climatic extremes. It may also provide a visual barrier to undesirable views beyond the wetland. Tall trees provide shade for open water areas and crags for bird roosting. The amount of leaf litter entering from the terrestrial zone must be considered in terms of water quality functioning and shade requirements may need to be balanced against dense growth of wetland plants where they are appropriate.

Water level management is the key to determining the success of vegetation. While wetland plants can tolerate temporary changes in water depth, care should be taken not to exceed the tolerance limits of desired species for extended periods of time (Davis 1995).

General wetland planting specifications include:

- Wetland planting should be carried out in early spring (September to October) or early autumn (from March) when water temperature are warm and plants are growing vigorously.
- No fertiliser is to be used in wetland plantings.
- Topsoil on wetland shelves will require erosion control fabric or can be worked into subsoils and lightly compacted.
- Plants should initially be planted in water no deeper than 100mm, with a minimum 150mm of plant foliage above the water level (with water levels gradually increasing).
- Plants should be firmly planted to a minimum depth of 40mm within the substrate to anchor the plant so that they are less prone to uprooting or floating. A minimum 250mm of plant foliage shall extend above the topsoil.
- Vegetation that is intended as a physical barrier may require a temporary fence (e.g. 1.2 m high silt fence) until it has established.
- Where pukekos are a concern, plants should be PB3 container size (1.5L) or greater or staked in place with biodegradable stakes at 45 degrees.

The accompanying plant lists are divided by plant size (groundcover, shrubs and tall grasses, and trees). Additional species for biodiversity appear at the end of the plant list, which can be integrated into gaps and edges, but are likely be too slow to establish or require too much additional maintenance to be considered for mass planting.

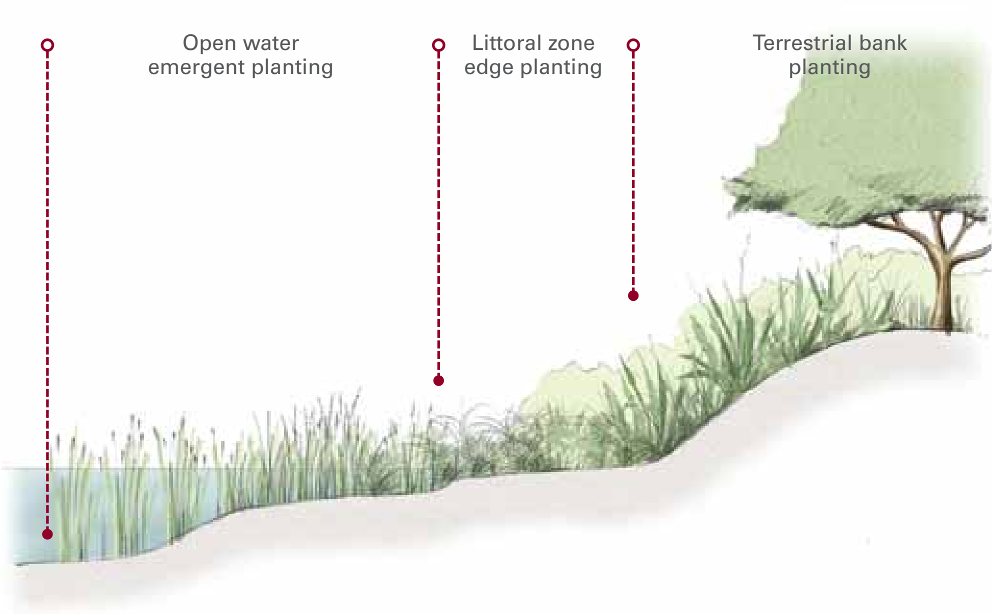


Figure 55: The three planting zones that provide for the function of stormwater wetlands and ponds

GENUS	SPECIES	COMMON NAME	PLANTING ZONE	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES
PRINCIPAL WETLAND SPECIES: 0.01 - 1.00M								
Baumea	rubiginosa	Orange nut sedge	Emergent to Littoral	Sedge & Rush-like	1.00	1.50	☀ ⛅	Slender green rush-like foliage. Creeping rhizome in swamps helps erosion control and acts as a water purifier. It can be identified by the orange seeds.
Baumea	tenax	Bumblebee nut sedge	Emergent to Littoral	Sedge & Rush-like	1.00	1.50	☀ ⛅	Rigid dark green foliage. Slow spreading to form tufts even in bogs and scrub of low fertility. Tolerates a wide range of conditions.
Baumea	teretifolia	Pakihi rush	Emergent to Littoral	Sedge & Rush-like	1.00	1.50	☀ ⛅	Vigorous growth spreading by rhizome with dark-green foliage in swamps, scrub and pakihi of low fertility.
Blechnum	novae-zelandiae	Kiokio	Littoral to Terrestrial	Fern	1.00	2.00	☀ ⛅ ☁	Very hardy. New fronds pink in the sun. A popular fern for re-vegatation and ornamental plantings
Carex	lessoniana	Spreading swamp sedge	Littoral	Sedge & Rush-like	1.00	2.00	☀ ⛅	Green tussocks with a wide-creeping rhizome. Damp or swampy ground. Ideal plant for stabilising stream banks. This is the better Carex for Auckland. South of the Bombay Hills Carex geminata is the preferred species.
Carex	virgata	Purei	Littoral	Sedge & Rush-like	0.80	0.80	☀	Vigorous clumping fine-leaved, sharp edged, bright green tussock. A successful coloniser in dry and damp areas.
Eleocharis	acuta		Emergent	Sedge & Rush-like	1.00	1.00	☀	A wiry erect sedge with tufted rhizome. Culms normally 20cm but can grow up to 1m . Widespread on pool, stream & lake margins.
Ficinia	nodosa	Knobby club rush, Wiwi	Littoral	Sedge & Rush-like	1.00	1.50	☀	A fine green-orange sedge that forms fountain like clumps on dry rocky headlands around the coastline. Formerly called Isolepis nodosa.
Isolepis	prolifer		Littoral	Sedge & Rush-like	0.30	2.00	☀	Light bright green fleshy sedge. Fast-spreading and prolific particularly suited for marsh-wetland areas.
Machaerina	sinclairii	Tuhara, Pepepe	Littoral	Sedge & Rush-like	1.00	1.50	☀ ⛅	Bright green iris-like leaves. Tall flowering spike with graceful bronze seed head (summer). Excellent in shade.
Myriophyllum	Native local species	Water Milfoil	Emergent	Herb	0.15	0.50	☀	Forms good ground cover in damp areas. Will grow in ponds as an emergent deep water plant.
Polygonum	salicifolium	Tutanawai Swamp Willow Weed	Littoral	Herb	0.50	2.00	☀ ⛅	A soft perennial growing on the margins of muddy streams, swamps and pools. Often confused with exotic weed species.
1.00 - 3.00M								
Apodasmia	similis	Oioi, Jointed Rush	Littoral	Sedge & Rush-like	1.50	1.00	☀	Swamp plant of saline and freshwater habitats. Very tough in all conditions except heavy shade. Superb erosion control & filter.
Astelia	grandis	Swamp Astelia	Littoral	Lily & Iris-like	2.00	2.00	☀ ⛅ ☁	Olive green flax-like leaves. Large 2m clumps. Rare in Auckland.

Table 12: Wetland and wetland-pond plant schedule

GENUS	SPECIES	COMMON NAME	PLANTING ZONE	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES
Baumea	articulata	Jointed twig-rush	Emergent	Sedge & Rush-like	1.80	2.00		Sturdy upright bright green stems, will tolerate both dry soil & deep water. Graceful 2m, brown seed heads in summer .
Bolboschoenus	fluviatilis	Kukuraho	Emergent	Sedge & Rush-like	1.50	2.00		Summer-green perennial. Creeping bulbous rhizome tolerates both saline & fresh water.
Carex	secta	Purei, makura	Littoral	Sedge & Rush-like	1.50	2.00		Green swamp tussock. Can form a mop of foliage above a 1m trunk. Prefers damp sun but also tolerates dry shade.
Cortaderia	fulvida	Toetoe	Terrestrial	Grass	1.50	2.00		Smallest of the Cortaderia's. 2m tall drooping flower spike (spring/summer). Ideal as shelter or feature plant.
Coprosma	propinqua	Mingimingi	Littoral	Shrub	3.00	2.00		Divaricating shrub with a range of forms, but all small-leaved. The female has blue fruit. Frequently a swamp dweller.
Coprosma	tenuicaulis	Hukihuki	Littoral	Shrub	2.00	1.00		Small-leaved compact swamp dweller. Fine grey foliage and black fruit. Excellent in damp conditions.
Cyperus	ustulatus	Giant umbrella sedge	Littoral	Sedge & Rush-like	1.50	2.00		Sharp-edged swamp grass. Fast growing with olive-green leaves. Ideal for revegetation of wetland margins.
Eleocharis	sphacelata		Emergent	Sedge & Rush-like	2.00	5.00		A vigorous rhizome spreading sedge that can form floating rafts & grows into deep (2m) open water.
Gahnia	xanthocarpa	Tupari maunga	Littoral	Sedge & Rush-like	3.00	3.00		Forms a large dark green clump. Cutting foliage. Drooping flower spikes to over 3m. Black nuts. Prefers swampy conditions.
Juncus	edgariae	Wiwi	Littoral	Sedge & Rush-like	1.50	1.00		Forms tight clumps from wiry stems. Tolerates extremes of wet and dry for short periods. Was known as Juncus gregiflorus.
Juncus	pallidus	Giant Rush Wiwi	Emergent to Littoral	Sedge & Rush-like	1.70	2.00		Forms light green robust clumps. Creeping rhizome. Colonises barren damp areas and swamps.
Juncus	sarophorus	Wiwi	Littoral	Sedge & Rush-like	1.50	1.00		A vigorous species that will tolerate drier conditions and can be found in pasture.
Myrsine	divaricata	Weeping Mapou	Littoral to Terrestrial	Shrub	2.00	1.50		Attractive plant with several forms, some particularly weeping. Useful as a small specimen tree.
Phormium	tenax	Harakeke	Littoral to Terrestrial	Flax	3.00	3.00		Red flower stalk (3-4m summer). Vigorous sturdy growth. Tolerates wet and/or coastal conditions. Plant away from edge of lawn to avoid entangling the mower.
Schoenoplectus	tabernaemontani		Emergent	Sedge & Rush-like	1.50	2.00		Upright reed with a blue-green tone to foliage. Good for water treatment ponds or wetlands.
Typha	orientalis	Raupo	Emergent	Sedge & Rush-like	2.50	5.00		Classic Bulrush is vigorous spreading with pale green strap-like foliage which is summer green, i.e Deciduous. It can dominate wetlands.
Plagianthus	divaricatus	Salt Marsh Ribbonwood	Littoral	Shrub	2.00	1.50		Coastal estuary plant for brackish wetland environments. Forms a tangled reddish bush along shell banks. Extremely hardy and forms an elegant shrub in the garden.

GENUS	SPECIES	COMMON NAME	PLANTING ZONE	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES
TREES AND SHRUBS 3.00M+								
Aristotelia	serrata	Wineberry - Makomako	Terrestrial	Tree	5.00	2.00	Sun, Part shade	Attractive red tinted semi-deciduous foliage and pink flowers (spring). Both sexes required for berries to attract birds.
Carpodetus	serratus	Putaputaweta	Littoral to Terrestrial	Tree	5.00	3.00	Sun, Part shade	Attractive tree. Can be covered in small white flowers (summer). Prefers damp soils, sun or shade.
Coprosma	arborea	Mamangi	Terrestrial	Tree	6.00	3,00	Sun, Part shade, Shade	The largest Coprosma can form a large tree. It has olive coloured leaves turning yellow in winter. Birds love the glassy fruit on female plant.
Coprosma	robusta	Karamu	Terrestrial	Tree	5.00	3.00	Sun	Fast growing shrub ideal for re-vegetation projects. Birds enjoy the masses of orange fruit on female plants.
Cordyline	australis	Cabbage Tree	Littoral to Terrestrial	Tree	8.00	3.00	Sun, Part shade	A classic New Zealand icon with single stem and round head. Clusters of scented flowers (spring). Best planted at the back of a shrubbery to limit spread of old leaves.
Dacrycarpus	dacrydioides	Kahikatea	Littoral to Terrestrial	Tree	35.00	5.00	Sun, Part shade	Superb specimen tree that can grow in damp and open sites. Adult foliage is a soft bluish-green.
Dicksonia	squarrosa	Wheki	Littoral to Terrestrial	Tree Fern	5.00	2.50	Sun, Part shade	Wheki tree fern. Can form multiple slender stems. Prefers a little shelter. Fast growing.
Geniostoma	ligustrifolium	Hangehange	Terrestrial	Tree	4.00	3.00	Sun, Part shade, Shade	Frost tender but otherwise hardy in drier conditions and under other trees. Was known as Geniostoma rupestre.
Hebe	stricta	North Island Koromiko	Terrestrial	Shrub	4.00	2.50	Sun	Long pale green leaves and long white flower spikes (spring). Fast growing, good for revegetation projects. Prefers open habitats on forest margins.
Hoheria	populnea	Lacebark - Houhere	Terrestrial	Tree	6.00	3.00	Sun, Part shade	A fast growing graceful tree. Abundant scented flowers (autumn).
Knightia	excelsa	Rewarewa	Terrestrial	Tree	20.00	4.00	Sun, Part shade	Narrow habit. Good specimen tree. Tui enjoy the red bottle-brush-like flowers (spring).
Laurelia	novae-zelandiae	Pukatea	Littoral to Terrestrial	Tree	15.00	3.00	Sun, Part shade, Shade	Moderately slow growing. Attractive bright green leaves. Reddish new branchlets. Specimen tree for damp areas.
Leptospermum	scoparium	Manuka	Littoral to Terrestrial	Tree	4.00	2.00	Sun, Part shade	Abundant white flowers (spring). Very hardy. Sunny position, most soils. This species is being reclassified and will probably be renamed as several different species.
Libocedrus	plumosa	Kawaka	Littoral to Terrestrial	Tree	7.00	4.00	Part shade	Ornamental specimen tree similar to exotic conifers in appearance. Prefers sites with shelter and cool soil.
Macropiper	excelsum	Kawakawa	Terrestrial	Tree	4.00	2.00	Part shade, Shade	Matt-green heart shaped leaves used medicinally and much loved by a small native caterpillar which creates 'uniquely perforated' leaves. Hardy.
Melicytus	ramiflorus	Mahoe	Terrestrial	Tree	6.00	3.00	Sun, Part shade	Very fast growing. Good filler for shady sites. Very hardy. Beautifully scented flowers followed by purple berries.
Olearia	solandri	Coastal shrub daisy	Terrestrial Coastal	Shrub	4.00	3.00	Sun, Part shade	Excellent tree for the edge of tidal estuaries. Small yellowish leaves. Abundant fragrant flowers (autumn). Extremely hardy and can be kept clipped to a hedge.

GENUS	SPECIES	COMMON NAME	PLANTING ZONE	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES
Plagianthus	regius	Ribbonwood	Terrestrial	Tree	8.00	3.00		Graceful tree with delicate foliage which is semi-deciduous. Abundant small green flowers (spring).
Podocarpus	totara	Totara	Terrestrial	Tree	20.00	5.00		A very attractive specimen tree. Very hardy. The somewhat prickly foliage makes for an effective hedge.
Pseudopanax	arboreus	Five-finger	Terrestrial	Tree	5.00	3.00		Palmate leaf. Dense habit in sun. Dark purple fruit (spring). Prefers drier rich soils.
Rhopalostylis	sapida	Nikau	Terrestrial	Palm	5.00	3.00		The only mainland palm. Slower growing than off shore island forms, but equally elegant.
Schefflera	digitata	Pate	Littoral to Terrestrial	Tree	4.00	3.00		Good specimen tree with bold seven-finger foliage. Ideal for damp, shady sites. Fast growing. Masses of fruit for birds.
Sophora	microphylla	Kowhai	Terrestrial	Tree	6.00	4.00		Tangled zigzag juvenile stage taking up to 10yrs to flower. Eventually becoming a tall upright tree.
Syzygium	maire	Swamp Maire	Littoral	Tree	8.00	4.00		Erect specimen tree develops aerial roots and buttressed trunk. Needs swamp conditions. White flower - red fruit.
Vitex	lucens	Puriri	Terrestrial	Tree	12.00	6.00		Broad spreading lowland tree with sturdy trunk and branches. Open habit. Pink flowers and berries all year round.
ADDITIONAL SPECIES FOR GREATER BIODIVERSITY:								
Amphibromus	fluitans		Littoral	Grass	0.30	0.50		This critically endangered grass is more appealing to the conservationist or collector, as it may be mistaken for a weed. Best in a boggy area or round edges of ponds.
Azolla	filliculoides	Native water fern	Emergent Floating	Fern	0.01	1.00		This is an attractive red foliaged native water fern that floats on the water. It is fast and effective at absorbing nutrients and cleansing pools. Becoming rarer as it is being over whelmed by a similar exotic species.
Baumea	arthrophylla		Emergent	Sedge & Rush-like	1.00	10.00		This sedge is similar to Baumea rubiginosa but differing in the flower head and its nuts. It is uncommon in Auckland but can be used in any wetland that does not dry out.
Baumea	complanata	Shiny sedge	Emergent to Littoral	Sedge & Rush-like	0.70	1.00		Flattened bright green foliage. Forms very attractive clumps. Extremely rare in the wild - now uncommon in Auckland
Baumea	juncea	Blue coastal sedge	Emergent to Terrestrial	Sedge & Rush-like	1.00	1.50		Slender blue-green rush-like foliage. Creeping habit will tolerate impoverished water- logged soils.
Blechnum	minus	Swamp Klokio	Littoral	Fern	0.50	1.00		Similar to Blechnum novae zelandiae but smaller and normally found in damp to swamp conditions.
Bolboschoenus	caldwellii		Emergent	Sedge & Rush-like	1.00	3.00		A smaller version of B. fluviatilis. However the flower heads are quite different, as they are fatter and denser.

GENUS	SPECIES	COMMON NAME	PLANTING ZONE	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES
ADDITIONAL SPECIES FOR GREATER BIODIVERSITY:								
Carex	gaudichaudiana		Littoral	Sedge & Rush-like	0.40	1.00		A highly variable species with a densely tufted, creeping rhizome. Requires moist, open situation. Forms thick swards.
Carex	pumila	Blue dune sedge	Littoral	Sedge & Rush-like	0.30	2.00		Vigorous rhizome spreading sand sedge. Sunny well drained site
Centipeda	Local native species	New Zealand sneezewort	Littoral	Herb	0.01	0.30		An opportunist herb that colonisers the beds of freshly drained dams and ponds . It is shortlived but seeds rapidly to recolonise other damp areas.
Chara	Local native species		Emergent, Pond floor	Algae submerged	0.30	1.00		Chara & Nitella are bottom dwelling algae forming carpets on the floor of lakes and ponds.
Cotula	coronopifolia	Soldiers Buttons	Littoral Coastal	Ground Cover	0.10	0.50		Very fast growing. Hardy in coastal estuarine habitats. Largish yellow flowers (spring-summer).
Crassula	ruamahanga		Littoral	Ground Cover	0.04	0.50		An opportunistic species which can be expected to occur in any suitably damp, open habitat.
Cyclosorus	interruptus		Littoral	Fern	0.40	1.00		Endangered fern. Spreading rhizome growth habit. A species of geothermal habitats, and frost-free, coastal and lowland wetlands.
Deparia	petersenii		Littoral	Fern	0.40	1.00		Creeping semi-deciduous fern. Easy to grow. Prefers semi-shade and slightly moist conditions.
Dianella	haematica	Turutu	Littoral	Lily & Iris-like	0.50	1.00		A newly described species of Dianella which grows bigger than Dianella nigra. Slender flax-like leaves. Beautiful blue-purple berries (summer-autumn). Hardy in dry semi-shade.
Dichondra	brevifolia	Mercury Bay lawn	Terrestrial	Ground Cover	0.01	1.00		Far-creeping, very flat ground cover. Ideal no-mow lawn. Grows around the coast in bright sun / semi-shade.
Doodia	squarrosa		Littoral	Fern	0.30	0.40		Hardy fern with pink new fronds. Occurs in thermal areas as well.
Elatostema	rugosum	Parataniwha	Littoral	Ground Cover	0.50	1.00		Attractive purple tinted foliage for a damp, shady site. Excellent alongside shady stream banks and waterfalls.
Eleocharis	gracilis		Emergent	Sedge & Rush-like	0.30	1.00		A smaller growing form of Eleocharis that makes a good edging to ponds and drainage channels.
Gleichenia	Native local species	Tangle fern	Littoral to Terrestrial	Fern	0.50	1.50		Limited availability. Fronds wiry and interlacing. Creeping. Temperamental until well established.
Glossostigma	elatinoides		Emergent	Ground Cover	0.01	0.50		Can be submerged in water and useful as an aquarium plant. Small green leaves. Tiny white flowers (summer).
Gonocarpus	aggregatus		Littoral	Ground Cover	0.15	0.40		Dense green leaves with orange-bronze tinge.

GENUS	SPECIES	COMMON NAME	PLANTING ZONE	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES
ADDITIONAL SPECIES FOR GREATER BIODIVERSITY:								
Gratiola	sexdentata		Littoral	Ground Cover	0.20-0.50	1.00		A wetland plant on the edge of lakes and swamps. As a pond plant it will grow half a metre tall.
Gunnera	Local native species		Littoral	Ground Cover	0.05	0.50-1.0		Brownish foliage and bright red berries on a 10cm tall spike. Creeping in damp areas.
Hierochloe	redolens	Karetu, Holy Grass	Littoral	Grass	0.50	0.50		Scented grass with dark green blades and purplish leaf bases. Prefers a sheltered site and moist soil. A cosmopolitan species used around the world to provide scented satchets and dried arrangements. Extinct in the Auckland region
Histiopteris	incisa	Water Fern	Brackish Littoral	Fern	1.00	2.00		Bracken-like in habit with soft glaucous fronds. Prefers open glades in scrub areas, swamps and streams.
Isachne	globosa	Swamp Millet	Littoral to Emergent	Grass	1.00	1.00		A sprawling plant, Isachne threads through dense rushes and reeds and is often a dominant component of swamps and margins of pools
Isolepis	cernua		Littoral	Ground Cover	0.15	0.20		A small, tufted, short creeping dune reed. It is promoted as 'The Fibre Optic Plant' because of its bright green foliage.
Juncus	kraussii var. austaliensis	Sea rush	Littoral	Sedge & Rush-like	1.00	1.00		Forms dark green clumps. Coastal. Ideal for tidal estuary plantings where salt water is prevalent at times. Was J.maritimus australiensis.
Lachnagrostis	filiformis	Wind Grass	Littoral	Grass	0.50	0.30		This is a grass that's good for natural plantings as it will self-seed everywhere.It is being pushed out of its habitat in Auckland.
Lepidosperma	australe	Square-stemmed sedge	Littoral	Sedge & Rush-like	1.00	1.00		Bluish grey foliage on a slow creeping rhizome forms dense clumps on poor gumland soils.
Lepidosperma	laterale	Sword Sedge	Littoral	Sedge & Rush-like	1.00	1.50		A sedge of infertile gumland, sand dunes and wetlands. It grows as a leafy tuft with flattened leaves and flower spikes which are very sharp edged. Once established it does not require much maintenance or fertiliser.
Leptinella	aff. dioica	Shore Leptinella	Littoral	Ground Cover	0.10	1.00		A soft spreading groundcover in cool moist sites. L. dioica is extremely variable. Coastal and inland up to 1000 m a.s.l.. In the northern part of its range usually on the margins of saltmarshes.
Leptostigma	setulosa		Littoral	Ground Cover	0.10	0.50		Thin pale green leaves creating slight mounds. Vigorous. Was classified as a Nertera but renamed as this has dry seed capsules -not red fruit.
Lobelia	angulata	Panakenake	Littoral	Ground Cover	0.10	3.00		Probably NZ's most popular groundcover being vigorous growing and smothered in white flowers and red fruit.
Mazus	Local native species		Littoral	Ground Cover	0.04	0.40-1.00		Vulnerable wetland plants with dense lush green leaves withwhite or mauve flowers. Deserving to be more widely planted.

GENUS	SPECIES	COMMON NAME	PLANTING ZONE	DESCRIPTION	HEIGHT (M)	SPREAD (M)	SUN / SHADE	NOTES
ADDITIONAL SPECIES FOR GREATER BIODIVERSITY:								
Marratia	salicina	King Fern, Para	Terrestial	Fern	2.50	2.50		
Mimulus	repens		Emergent	Herb	0.15	0.50		A fleshy dull green plant with 1 cm pink flowers. Needs to be wet but is hard to establish. Limited availability.
Nertera	Native local species		Littoral	Ground Cover	0.10	1.00		Small glossy bright green leaves. Forms a tight mat. Red-orange berries.
Oplismenus	hirtellus	Basket Grass	Littoral	Grass	0.15	3.00		Prostrate grass with a loose spreading habit. Will tolerate light foot traffic.
Potamogeton	suboblongus	Rerewai	Emergent	Herb	0.05	0.30		An endemic aquatic plant with dark green leaves. Requires shallow water (no more than 5cm) or mud.
Potentilla	anserinioides		Littoral	Ground Cover	0.05	1.00		Bronze-leaved, tuft-forming plant with bright yellow 1.5cm flowers. May be deciduous during winter in cooler climates. Spreads quickly.
Ranunculus	acaulis		Littoral	Herb	0.01	1.00		An attractive member of the Buttercup family with fleshy green leaves and bright yellow flowers. It forms tight clumps.
Schoenoplectus	pungens		Emergent	Sedge & Rush-like	0.50	2.00		This sedge has distinctive triangular stems. Grows behind the sand dunes in damp hollows.
Schoenus	tendo		Littoral	Sedge & Rush-like	1.00	1.00		A fine rush like plant that goes orange in the sun and green in the shade. Can be temperamental during establishment, but very hardy on dry clay sites.
Sparganium	subglobosum		Emergent to Littoral	Herb	1.00	5.00		A fast growing plant that is usefull In wetland areas as it grows well in amoungst other plants. Common around the country but rare in Auckland. Attractive too.
Sphagnum	cristatum		Emergent	Moss	0.10	0.50		An attractive moss commonly used for hanging baskets and establishing epiphytes. This plant is much more attractive alive and well in a pot that sits in water.
Triglochin	striata		Emergent	Sedge & Rush-like	0.30	1.00		An attractive wetland plant along the shoreline of lakes, bogs and salt marshes. It can be semi-aquatic floating in dense swards as rafts in water 1 metre deep.
Ptisana	salicina	King Fern, Para	Terrestrial	Fern	2.50	2.50		Frost tender, tropical fern. Requires shade and damp soil. Good pot plant. Slow growing. Now renamed as Ptisana salicina as it is closely related to that tropical genus.

6.4 OPERATION & MAINTENANCE

Once vegetation has been planted, intensive maintenance will be required over the first year including watering, physical repairs, mulch, weed removal, and possible replanting.

Continual monitoring and maintenance will ensure wetland plants establish, and that both the aesthetic appearance and functional operation of the wetland or pond are secured. Corrective maintenance may also be required including slope and erosion repairs. Ongoing management and maintenance of stormwater wetlands or pond is likely to include:

- Inspection of structures for blockage by plants, mulch, or algae.
- Monitoring sediment accumulation around plants and at inlets and outlets.
- Regular checks for problem weeds to arrest early invasions when controls are relatively easy.
- Checks for insect pests, particularly midges and mosquitoes.
- Supplementary watering, potentially by siphoning or pumping from pre-treatment ponds.
- General observations on water quality, algae, clarity, odour, insects, vandalism etc, including photos from fixed points.
- In the event of a perceived water quality issue, implement a water quality monitoring programme to sample water levels and target contaminants. This will determine what management actions to take.
- Flooding will cause plants to be scoured from a wetland and/or drowned. If a large area of plants is lost (>5 m^2), re-establishment will need to be carried out. Small areas will generally recover naturally.

WETLAND-POND													
"SOFT" LANDSCAPE MAINTENANCE SCHEDULE													
MAINTENANCE (AS REQUIRED)	GROWING SEASON												AT COMPLETION
	SPRING			SUMMER			AUTUMN			WINTER			
	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	
PLANTS													
STAKING	MONTHLY												
TRIMMING AND PRUNING													
HEDGE TRIMMING													
WEED CONTROL													
WATERING				TWICE WEEKLY									
REPLACEMENT													
WETLAND REPLACEMENT													
OVER SOWING													
GRASS AREAS													
MOWING	TWICE MONTHLY			MONTHLY			MONTHLY			MONTHLY			
FERTILISER													
WEED CONTROL													
MULCH REPLENISHMENT													
OTHER													
LITTER REMOVAL	MONTHLY												
MULCH REPLENISHMENT													
REPAIR EROSION													
DRAINAGE													
PET WASTE REMOVAL	MONTHLY												

Table 13: Wetland and wetland-pond operation and maintenance programme

REFERENCES & BIBLIOGRAPHY

N.B References and links for weed and pest management appear in the relevant section

Anon 2009 Building soil: Guidelines and resources for implementing Soil Quality and Depth Best Management Practice T5.13 in WDOE Stormwater management Manual for Western Washington. 2009 Edition. www.SoilsforSalmon.org

Auckland Regional Council (ARC), 2003 Technical publication 10, Design Guideline Manual: Stormwater Treatment Device. Auckland Regional Council

Martin, T; Barham, J; Reeves, P. (2008). Making the Most of Auckland's Stormwater Ponds, Wetlands and Rain Gardens. Prepared by Wildland Consultants for Auckland Regional Council.

Bioengineering Group, Inc. (2003). Operation and Maintenance Manual. Western Branch Putuxent River LID Retrofit Project. Prince George's County, Maryland.

Boffa Miskell (2007). Restoring Our Native Plants. Prepared by Boffa Miskell Limited for Manukau City Council.

Boubee, J., E. Williams & J. Richardson (2000). Fish passage guidelines for Auckland Region. Auckland Regional Council TP 131.

Bracey, S.; Scott, K.; Simcock, R. (2009). Talbot Park Community Renewal project – integrating low-impact urban design. Sixth South Pacific Stormwater Conference, 28-30 April 2009, Auckland.

Brenneisen, S. (2006). Space for urban wildlife: Designing green roofs as habitats in Switzerland. Urban Habitats 4(1): 27-36.

Brisbane City Council, 2005 Draft Water Sensitive urban Design Engineering Guidelines

Brisbane City Council, 2006, Stormwater Gardens Bioretention Basins for Urban Streets

Brix, H. 1993. Wastewater treatment in constructed wetlands system design, removal processes, and treatment performance. Pp. 9-22 in Constructed Wetlands for Water Quality Improvement, G. A. Moshiri (ed). Boca Raton, Fla.; CRC Press, 632 pp.

Burgess, H (2004). An assessment of the potential of green roofs for bird conservation in the UK. BSc Hons Geography Thesis, University of Sussex.

City of Melbourne, 2004 Water Sensitive Urban Design Guidelines

City of Sydney, 2004. Water sensitive design in Sydney region, Technical Guide WCC (2004). Stormwater Solutions for Residential Sites. Waitakere City Council.

Colwell, S.R.; Horner, R.R.; Booth, D.B. (2000). Characterization of performance predictors and evaluation of mowing practices in biofiltration swales.

Craul, P.J. 1999. Urban Soils: applications and practices. John Wiley & Sons Inc., New York

Davis, L. (1995). A Handbook of Constructed Wetlands: A Guide to Creating Wetlands for Agricultural Waste, Domestic Wastewater, Coal Mine Drainage and Stormwater in the Mid-Atlantic Region. General Considerations. Natural Resources Conservation Service, US Environmental Protection Agency-Region III and the Pennsylvania Department of Environmental Resources, Washington, DC, Vol. 1.

Douglas, E.M.K. (1984). Waiora, Waikino, Waimate, Waitai: Maori perceptions of water and the environment. Occasional Paper No. 27. Centre for Maori Studies and Research, University of Waikato, Hamilton.

Dunnett, N.; Clayden, A. (2007). Rain Gardens: Managing Water Sustainability in the Garden and Designed Landscape. Timber Press, Portland.

Dunnett, N.; Kingsbury, N. (2008). Planting Green Roofs and Living Walls. Timber Press, Portland.

EPA (2000). Guiding principles for constructed treatment wetlands: Providing for water quality and wildlife habitat. United States Environmental Protection Agency.

Facility for Advancing Water Biofiltration, 2006, Bioretention and Tree pit media specification

Federal Highway Administration. Roadside revegetation. An integrated approach to establishing native plants. http://www.nativerevegetation.org/learn/manual/ch_1.aspx. Accessed April 2009

Gedge, D.; Kadas, G. (2005). Green roofs and biodiversity. Biologist 52 (3): 161-169.

Grant, G. (2006). Extensive green roofs in London. Urban Habitats 4(1): 51-65.

Grant, G.; Engleback, L.; Nicholson, B. (2003). Green Roofs: their existing status and potential for conserving biodiversity in urban areas. English Nature Research Reports Number 498. English Nature, UK.

Hanks D. And Lewandowski, A (undated) Protecting urban soil quality:examples for landscape codes and specifications. http://soils.usda.gov/sqi/management/files/protect_urban_sq.pdf accessed April 2009

Headley, T.R & Tanner, C.C. (2006). Application of Floating Wetlands for Enhanced Stormwater Treatment: A Review. Auckland Regional Council

Hewitt AE 1998. New Zealand soil classification. Landcare Research Science Series 1, 2nd ed. Lincoln, Manaaki Whenua Press. 133 p

Hewett A. 2004. Soil properties for pant growth. Manaaki Whenua Press, Landcare Research Science Series, no. 26. 22 p. (www.mwpress.co.nz/store) accessed April 2009

Hostetler M. and Drake D. 2008: Conservation subdivisions: a wildlife perspective. Landscape and Urban Planning 90 (3-4): 95-101 (www.sciencedirect.com)

IDEQ Storm Water Best Management Practices Catalog (2005)

Ignatieva M., Meurk C., van Roon M., Simcock R., and Stewart G. 2008. How to put nature into our neighbourhoods: application of Low Impact Urban Design and Development (LIUDD) principles, with a biodiversity focus, for New Zealand developers and homeowners. Manaaki Whenua Press, Landcare Research Science Series, no. 35. 52 p. (www.mwpress.co.nz/store) accessed April 2009

Kadas, G. (2006). Rare invertebrates colonizing green roofs in London. Urban Habitats 4(1): 66-86.

Kidd, J. (2005). Water Sensitive Urban Design: Optimum Green Roof for Brisbane. http://www.greenroofs.com/pdfs/student-OptimumGreenRoofforBrisbane.pdf

Land and Water Constructions, 2006 Kingston City Council and Better Bays and Waterways -Institutionalising Water Sensitive Urban Design and Best Practice Management Project Review of street scale WSUD in Melbourne – Study Findings

Malcolm, M. & M. Lewis (2008). North Shore City Bioretention Guidelines. North Shore City Council.

Ministry of Justice 2005. Crime Prevention Through Environmental Design; http://www.justice.govt.nz/pubs/reports/2005/cpted-part-1/index.html

North Carolina DENR. 1997. Stormwater Best Management Practices Manual. Raleigh, N.C.: North Carolina Department of Environment and Natural Resources. Division of Water Quality. 85 pp.

North Carolina State University, North Carolina A&T State University, U.S. Department of Agriculture, and local governments cooperating: Designing Rain Gardens (Bio-Retention Areas)

North Shore City Council, 2005 Long Bay Practice notes 204 – Rain gardens

Prince George's County, Maryland, The Bioretention Manual

Russell, R. & L. Kuginis (1998). Mosquito risk assessment and management. In: The Constructed Wetlands Manual. Department of Land and Water Conservation, New South Wales.

Sainty, G. & M. Beharrell (1998). Wetland plants. In: The Constructed Wetlands Manual. Department of Land and Water Conservation, New South Wales.

Schaffer, B. & S. Barnsley (1998). Design of wetlands for recreation and visual amenity. In: The Constructed Wetlands Manual. Department of Land and Water Conservation, New South Wales

Simcock R., Smale M. and Meurk C. 2005. Maintaining and revegetating roadsides: a handbook for road controlling authorities and contractors. Landcare Research NZ Ltd. Free *.pdf at http://icm.landcareresearch.co.nz/knowledgebase/publications/documents/Road_reveg_handbook_31_Aug_2005.pdf accessed April 2009

Simcock R. 2007: The hydrological effect of compaction associated with earthworks. Landcare Research Contract Report: 0607/112 for ARC

Tanner, C.C., P.D. Champion & V. Kloosterman (2006). New Zealand Constructed Wetland Planting Guidelines. National Institute of Water and Atmospheric Research report published in association with the New Zealand Water & Wastes Association (available from http://www.nzwwa.org.nz/Constructed_Wetland_Planting_Guidelines.pdf)

Tanner, C.C. & V. Kloosterman (1997). Guidelines for Constructed Wetland Treatment of Farm Dairy Wastewaters in New Zealand. NIWA Science and Technology Series No. 48.

USEPA (2000). Guiding Principals for Constructed Treatment Wetlands: Providing for Water Quality and Wildlife Habitat. US Environmental Protection Agency, Office of Water.

Villarreal, E.L. (2005). Beneficial Use of Stormwater: Opportunities for Urban Renewal and Water Conservation. Doctoral Thesis, Department of Water Resources Engineering, Lund Institute of Technology, Lund University, Coden.

WCC (2005). Native to the West: A Guide for Planting and Restoring the Nature of Waitakere City. Waitakere City Council.

WCC (2000). Waitakere City Draft Comprehensive Urban Stormwater Management Strategy and Action Plan. http://www.waitakere.govt.nz/abtcnl/pp/cussap.asp

Williams, P., Biggs, J., Whitfield, M., Thorne, A., Bryant, S., Fox, G. and Nicolet, P. (1999). The pond book: a guide to the management and creation of ponds. The Ponds Conservation Trust, Oxford

Wetlands International (2003). The use of constructed wetlands for wastewater treatment. Wetlands International, Malaysia.

Wiese, R., S. Raft & G. White (1998). Detailed component design. In: The Constructed Wetlands Manual. Department of Land and Water Conservation, New South Wales.

Winning, G. & M. Beharrell (1998). Design of habitat wetlands, wetland rehabilitation. In: The Constructed Wetlands Manual. Department of Land and Water Conservation, New South Wales.

WSUD (2006). Water Sensitive Urban Design Technical Design Guidelines for South East Queensland.