Water Sensitive Design for Stormwater

March 2015
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Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Cover image: Bayside Reserve, Browns Bay, Auckland
Photographer: Simon Devitt

Preface

Water Sensitive Design for Stormwater

This document, *Water Sensitive Design for Stormwater*, known as GD04, provides guidance for the application of water sensitive design (WSD) to land use planning and land development, with a specific focus on stormwater and freshwater management.

WSD applies a set of principles to land development to reduce or minimise negative effects on the environment.The emphasis is on the appropriate location, layout and design of development, including its context within the broader catchment and region. WSD can be applied at multiple scales, for structure planning, subdivision and site development, and is appropriate for both greenfield sites and brownfield redevelopment.

A WSD approach takes into account the multiple objectives influencing project outcomes, including urban design, landscape amenity, and community issues and aspirations. In this way, stormwater management is targeted to where the greatest benefit can be achieved, both for the community and the land developer, and is an integral component of good urban design.

New approaches adopted by GD04:

Guidance on low impact design (LID) was previously provided by the Auckland Regional Council Technical Publication TP124 *Low Impact Design Manual for the Auckland Region* (2000). GD04 is an update of this document and includes the following new material:

1. A change in focus from LID to WSD and reframing to provide emphasis on freshwater management, particularly stormwater management, throughout all phases of land use planning, design and development
2. A WSD definition and set of principles
3. An analysis of challenges to WSD implementation
4. A discussion of synergies and conflicts between WSD and urban design principles
5. Application of WSD principles to brownfield environments

Extensive consultation was undertaken to develop GD04. Early in the development of this document, three consultation groups were tasked with providing the following specific input:

1. An internal Auckland Council technical review group provided the overarching direction of the document and helped to guide the focus of content within GD04.
2. A representative stakeholder group external to Auckland Council provided detailed guidance towards the practical application of content within GD04.
3. A group of local and internationally recognised WSD (or similar) practitioners provided independent peer review of the document. The international practitioners ensured that the content of GD04 was aligned with international best practice, while independent local peer reviewers ensured that its content remained relevant to New Zealand and the Auckland region.

For your comments and suggestions, please fill in a feedback form downloadable from http://www.aucklanddesignmanual.co.nz/design-thinking/wsd/documents and send to wsd@aucklandcouncil.govt.nz.

Acknowledgements

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St Patricks Square, Auckland

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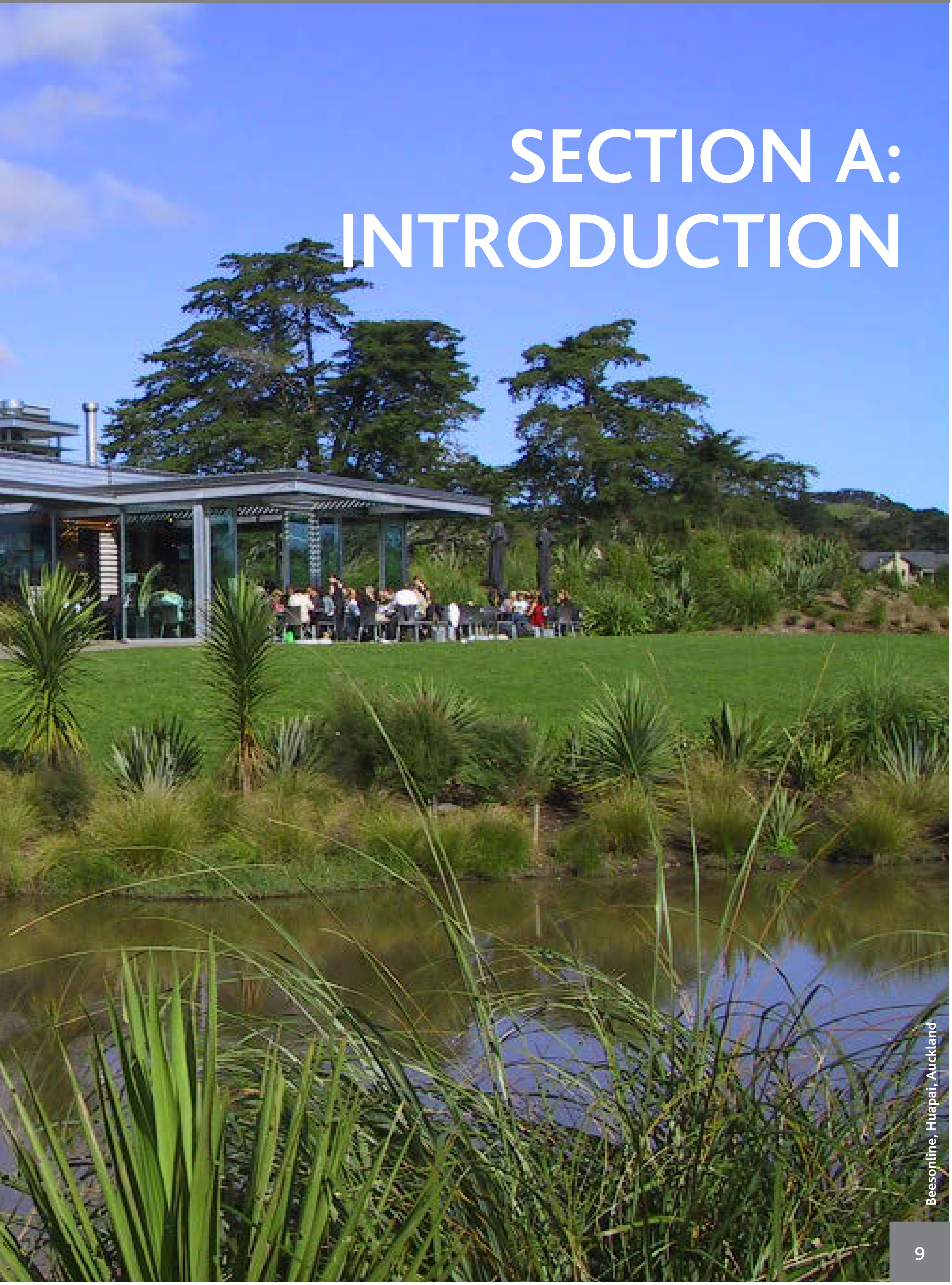
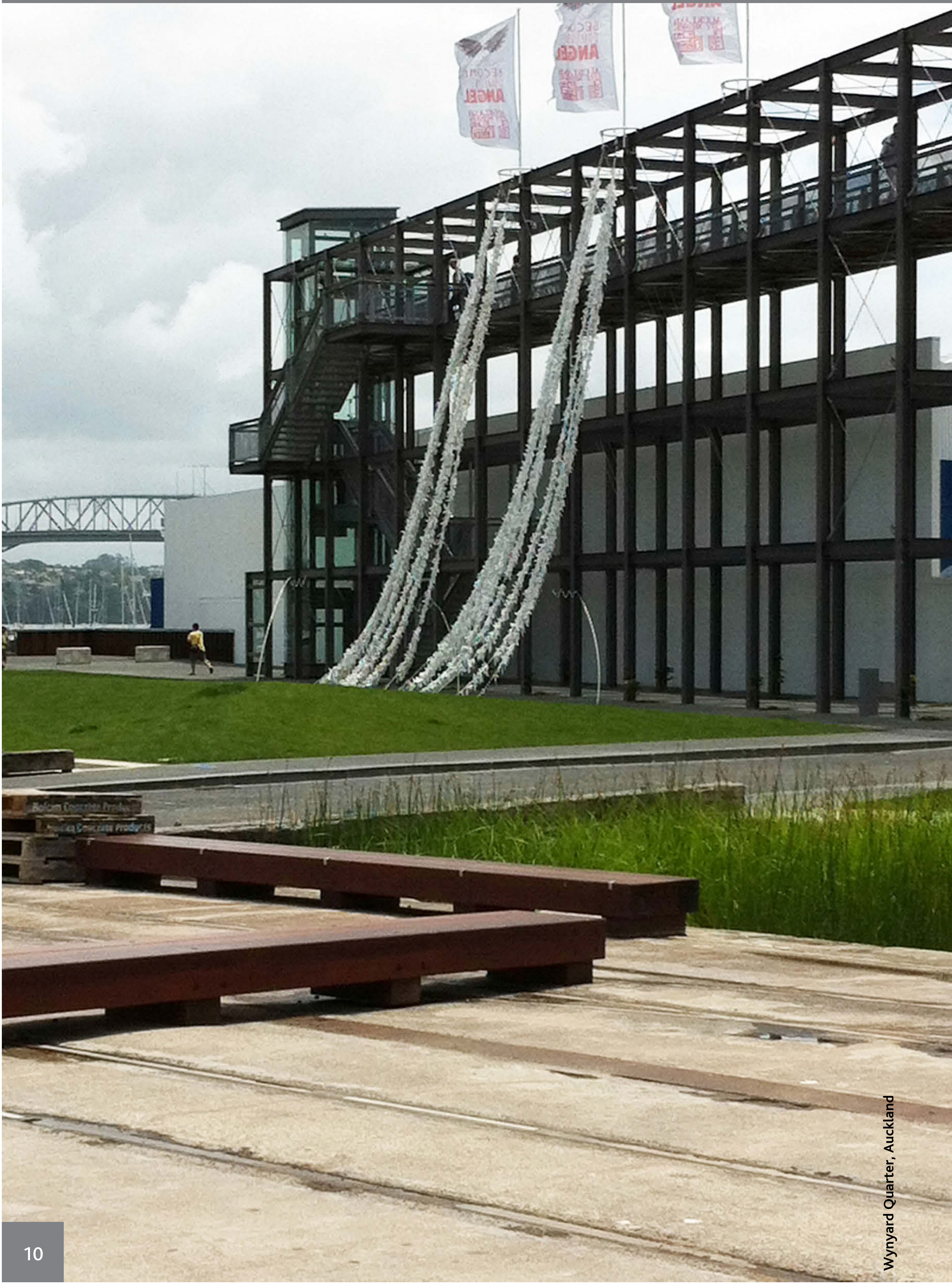
The Groynes Reserve, Christchurch

SECTION A: INTRODUCTION



Beesonline, Huapai, Auckland



Wynyard Quarter, Auckland

A1.0 Introduction

Auckland's population is expected to increase by over one million people in the next 30 years, which will see as many as 400,000 new homes built (Auckland Council, 2012). At the same time, The Auckland Plan (2012) sets the vision of Auckland becoming the 'world's most liveable city'. This places an emphasis on sustainable urban development to accommodate population growth, while ensuring communities are safe and healthy environments to live, work and play.

Water sensitive design (WSD) is essential to support the vision of The Auckland Plan. It promotes land use planning practices that balance land development with the ecosystem services necessary to support it. Ecosystem services are the benefits people receive from nature, and are categorised as provisioning, regulating, cultural and supporting (Millennium Assessment, 2005). This balance between land development and ecosystem services ensures the resilience of our region's environment and in particular the values and sensitivities of our harbours and watercourses.

WSD is an inter-disciplinary design approach, which considers stormwater management in parallel with the ecology of a site, best practice urban design, and community values. WSD aspires to ensure multiple public benefits from stormwater management and to develop a unique 'sense of place' for our communities. It also seeks to deliver low risk and better return on investment for land developers.

This guideline document, *Water Sensitive Design for Stormwater*, known as GD04, introduces the principles and objectives for WSD and guides the practitioner through a design programme for land development. WSD can be applied to development scenarios in both greenfield (undeveloped) and brownfield (previously developed) situations.

A WSD approach in a greenfield environment directs development to appropriate areas of a catchment, and provides for intensified or clustered development in these locations to minimise land disturbance and earthworks. The result is an effective balance of protected and enhanced natural environments and associated ecosystem services to support the proposed development, and more broadly the life-supporting capacity of our communities.

In a brownfield situation WSD promotes the integration of ecosystem services into the existing built form. This may be responding to existing environmental concerns on a site, to allow for intensified land use activity, or to enhance environments within and adjacent to the site. Reconstruction of buildings can be congregated within the site to provide space to retrofit ecosystem services. These opportunities may include the construction of raingardens, living roofs and swales, mass tree planting, remediation of existing or contaminated soils, rehabilitation of watercourses and wetlands, and stream daylighting.

A2.0 Definition of WSD for stormwater

WSD is defined in the Proposed Auckland Unitary Plan (PAUP) as follows:

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

In the Auckland region, WSD represents the best practice approach for stormwater management, taking into consideration whole-of-life costs. Similar design paradigms are promoted in Australia (water sensitive urban design, WSUD), the United States (low impact development, LID) and the United Kingdom (sustainable drainage systems, SuDS). This guideline captures elements from these approaches, while reinforcing the unique drivers for New Zealand environments, and specifically the Auckland region.

This guideline focuses on stormwater management in particular, and does not provide guidance on the water supply and conservation aspects of WSD.

WSD provides an approach which will contribute to achieving the vision and strategies of The Auckland Plan. It is supported by rules in the PAUP, and this GD04, along with technical guideline documents, will assist in the implementation of WSD.

Uptake of WSD will be monitored to allow understanding of both the success of implementation and the physical effects on the freshwater and marine receiving environments.

Water Sensitive Design for Stormwater

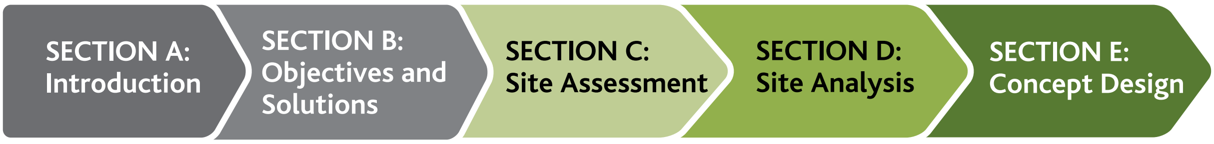


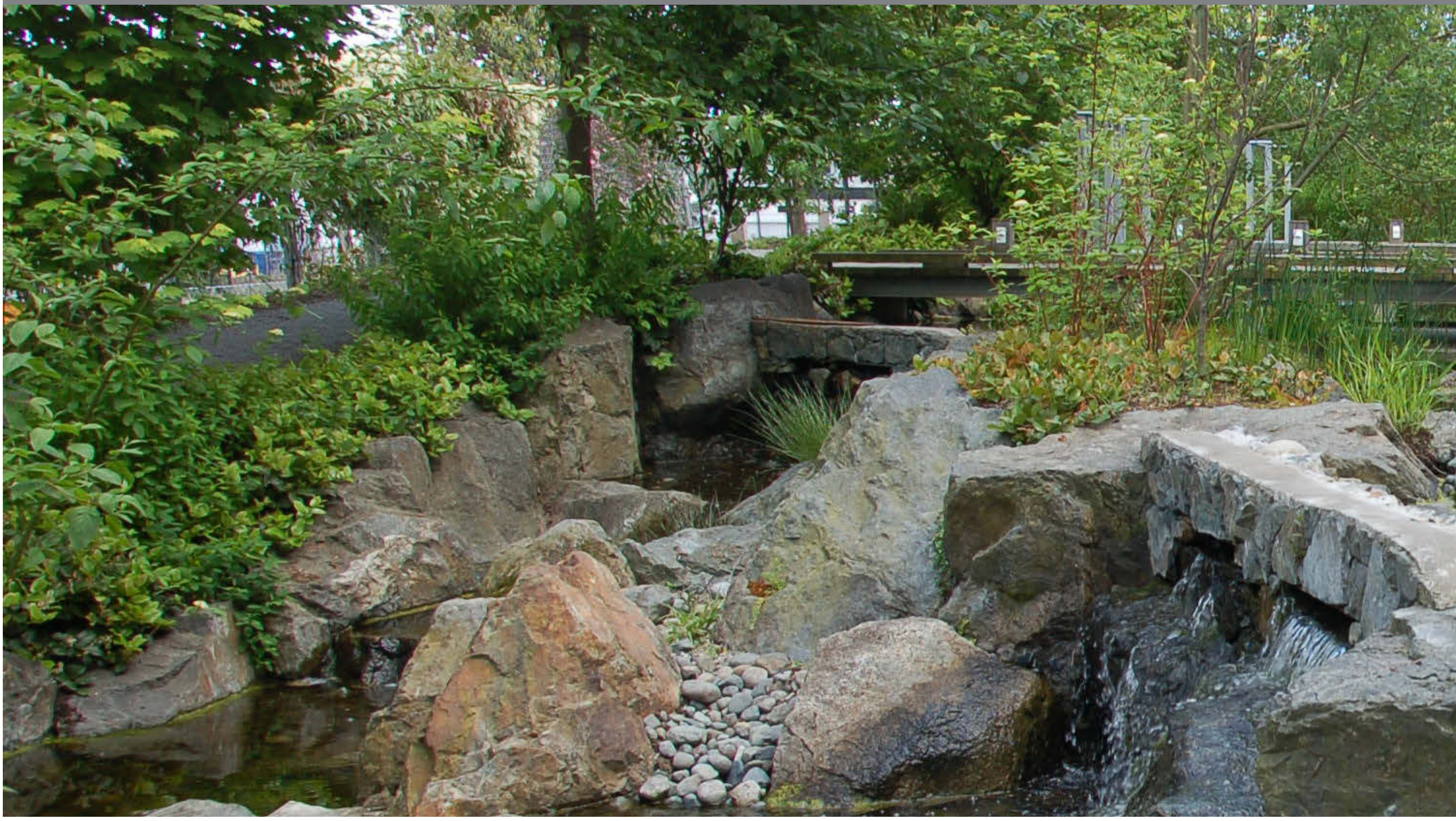
Figure 1: Outline of GD04

A3.0 How to use GD04

The intended audience for GD04 includes policy planners, stormwater engineers, landscape architects, and other design practitioners associated with land development and land use planning where stormwater and freshwater management is a consideration. The outline of this document is illustrated in Figure 1.

Section B of GD04 defines the objectives of WSD and explains the multiple drivers for WSD as Auckland Council's preferred approach to stormwater management. The key audience for Section B is policy planners, regulators, and those preparing related materials on stormwater management. However, anyone seeking a clear understanding of WSD in the Auckland context would benefit from reading this section.

Sections C to E have a structure that follows the design process for land development. Sections C and D focus on-site assessment and site analysis, respectively. Section E develops the WSD concepts. The key audience for these sections is land developers, land use planners, and their consultants.



A4.0 WSD principles for stormwater

A set of WSD principles for stormwater are provided below to complement the WSD definition and offer further guidance for land use planning and land development. Note that even with the application of these principles, WSD is not a universal solution for land use change, and some sites or receiving environments may be considered too sensitive and/or their existing values too significant to allow development.

A4.1 Promote inter-disciplinary planning and design

A project team should consider WSD principles as early as possible in the planning and design process. A WSD approach requires the input and skill of a range of disciplines such as engineering, landscape architecture, urban design, community engagement specialists, planning and ecology, and is normal best practice in this regard.

By undertaking a design that is inclusive of a range of disciplinary fields, a project team can identify project risks and opportunities early in the design process, and can deliver multiple and complementary environmental, economic and social benefits from stormwater management.

A4.2 Protect and enhance the values and functions of natural ecosystems

WSD aims to protect existing natural systems such as mature vegetation, aquifers, watercourses and wetlands for their stormwater management function. WSD also seeks to protect and enhance the beneficial properties of existing soils and subsoils, such as organic content and permeability.

The best means to protect natural systems and processes is through clustering land development on the most appropriate development sites in a catchment, limiting land disturbance and earthworks, and ensuring a balance of protected, enhanced and resilient ecosystem services.

Dockside Green, Victoria, Canada

A4.3 Address stormwater effects as close to source as possible

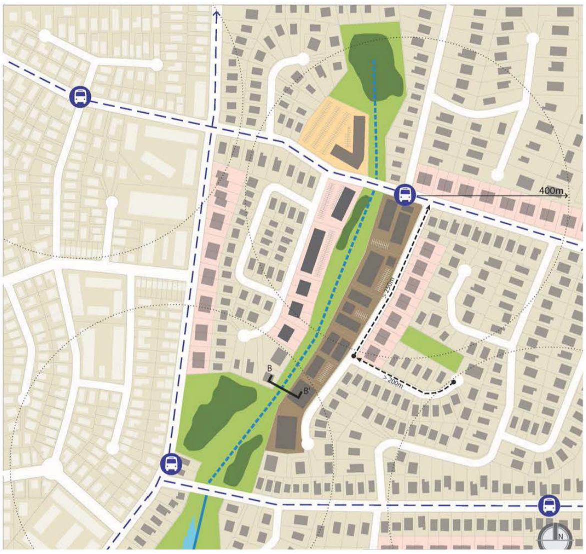
WSD aims to limit impervious surfaces, such as roading and building footprints, that generate stormwater runoff. This may be achieved through intensifying or clustering development in appropriate areas of a catchment and/or through site-specific planning and design responses.

A WSD approach can also reduce 'effective' imperviousness by directing stormwater runoff to pervious mitigation areas in order to retain/detain and treat stormwater prior to entering reticulated networks or the receiving environment. This alleviates the potential downstream environmental effects from stormwater volumes, peak flows and contaminants. It also reduces the requirements for lower catchment stormwater infrastructure to manage these effects.

A4.4 Mimic natural systems and processes for stormwater management

Natural systems, such as forests and streams, retain, infiltrate and transpire stormwater runoff and capture and transform contaminants. Treatment of contaminants occurs at the interface of soil, water and plant systems, including physical (e.g. filtration), biological (e.g. microbial action), and chemical (e.g. cation exchange) processes.

WSD promotes the restoration of natural systems and processes and their associated ecosystem services as part of catchment development. This includes the integration of these processes into engineered devices, such as treatment wetlands, swales, living roofs, raingardens and tree pits.

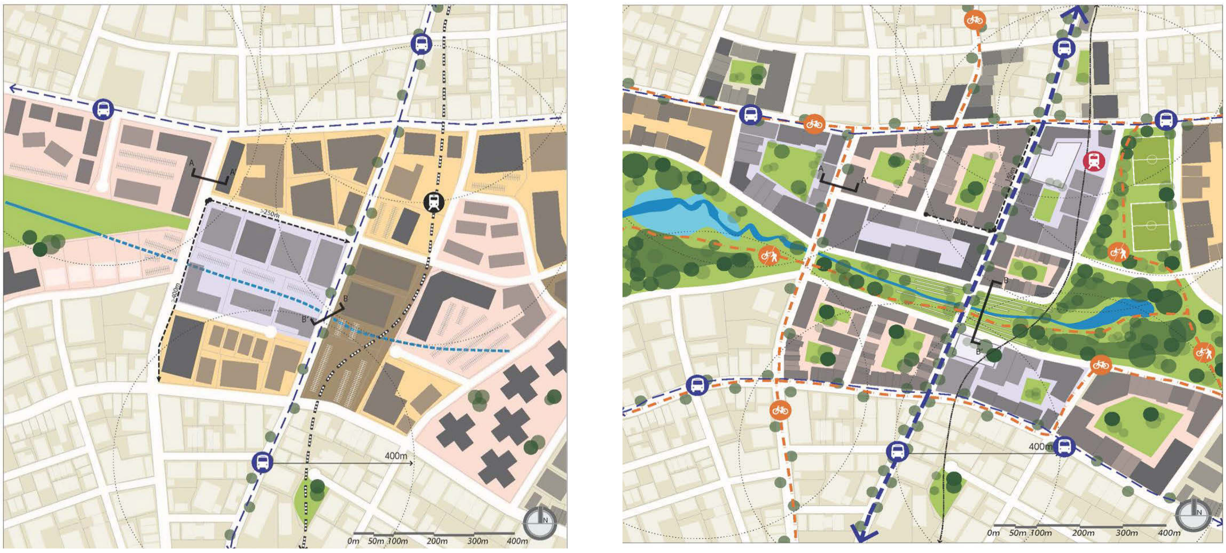


A5.0 Conventional vs. WSD approaches to stormwater management

'Hard' stormwater infrastructure, such as pipes and concrete channels, is a means to convey stormwater runoff in order to manage flood risk to property and people. However these structural elements are often a source of adverse effects on the environment, by rapidly concentrating stormwater flows and their contaminants to the receiving environment. Their effectiveness is also limited by system capacity (e.g. pipe diameter).

WSD approaches focus on reducing or eliminating stormwater runoff generation through source control, and utilising natural systems and processes to manage stormwater quantity and quality effects. WSD is inherently a context-specific approach which utilises a combination of conventional stormwater infrastructure, WSD devices (e.g. swales and raingardens), and enhanced natural systems to achieve the best practical stormwater management outcome. This includes the potential to utilise stormwater as a supply for potable water or irrigation.

WSD is a design approach based on a set of guiding principles. WSD is therefore applied as 'best fit' for the planning or design context. In a greenfield situation, especially where there are valuable and sensitive environments, the benefits of protecting natural resources are significant. In a brownfield or redevelopment scenario, there may be significant existing built constraints, fixed costs (i.e. existing assets), and limited existing natural resources. However, this does not limit the potential for the principles of WSD to be realised through innovation and appropriate site design. This may include working with the configuration or height of buildings to provide the greatest development yield for their footprint, the retrofit of living roofs, living walls and pervious paving, or integrating vegetation into the redeveloped site to enhance ecosystem services.



Low and high achievement WSD scenarios (Easton & Marshall, 2013)

A6.0 Statutory context

The statutory context in the Auckland region has changed dramatically following the amalgamation of the former regional council and the seven city/district councils into a single unitary authority. This has also occurred amidst a backdrop of nationwide reform to key statutes such as the Resource Management Act 1991 (RMA) and the Local Government Act 2002 (LGA). Key legislation influencing WSD outcomes is introduced below.

A6.1 The Resource Management Act 1991 (RMA)

The RMA has a single key purpose: to ensure that natural and physical resources are sustainably managed for present and future generations. This sustainable management purpose, and its associated principles, underpins all decisions made under the RMA.

Auckland Council has prepared a unitary plan, the Proposed Auckland Unitary Plan (PAUP), to address its statutory requirements, including controls for development, subdivision and stormwater management. The PAUP was released as a publicly notified proposed plan in September 2013. The PAUP gives effect to strategic direction on resource management set at the national level through the National Policy Statements (NPS) and National Environmental Standards (NES). The government has signalled an intention to provide more national guidance on resource management. The existing NPSs of relevance are:

- NPS - NZ Coastal Policy Statement (managing coastal areas)
- NPS - Freshwater Management (managing water resources)
- Hauraki Gulf Marine Park Act, Sections 7 and 8 (managing the Hauraki Gulf).

Auckland Council is currently working on the planning phase for the NPS - Freshwater Management. It is anticipated that this work will form the Council's overarching freshwater planning framework, and that programmes such as WSD will be continued as part of the implementation of the Policy. The setting of freshwater management units, attributes and limits will be included in the PAUP once agreed, and might have implications for WSD implementation.

A6.2 The Local Government Act 2002 (LGA)

Significant changes were made to the LGA 2002 in 2012. This included a new Section 10 relating to the purpose of local government as follows:

(1) The purpose of local government is:

(a) to enable democratic local decision-making and action by, and on behalf of, communities; and

(b) to meet the current and future needs of communities for good-quality local infrastructure, local public services, and performance of regulatory functions in a way that is most cost-effective for households and businesses.

(2) In this Act, good-quality, in relation to local infrastructure, local public services, and performance of regulatory functions, means infrastructure, services, and performance that are:

(a) efficient; and

(b) effective; and

(c) appropriate to present and anticipated future circumstances.

A6.3 Other key documents

There are a number of other statutory and guideline documents discussed below that influence the use of WSD as a design approach for land development and stormwater management.

Building Act 2004

The strict standards applied by the Building Act mean that design solutions, even those which have already received resource consent, may need further modification to accommodate building code requirements. In this manner, WSD design approaches may conflict with standardised codes and require additional technical assessment.

Health and Safety in Employment Act 1992

Requirements under this Act may conflict with WSD design solutions. Conflicts may be in terms of safe construction and safe ongoing operation, which may require additional technical assessment.

Reserves Act 1977

The Reserves Act is the primary piece of legislation for administering reserves. Its purpose includes providing for the preservation and management of areas that have ecological, landscape, natural, scenic, historic or cultural values, and existing or potential recreational use for public benefit and enjoyment.

The Act requires that reserves must be classified according to their principal or primary purpose. This requirement ensures that they are used, managed and developed appropriately. The majority of reserves in Auckland are classified as ‘recreation’, ‘scenic’, ‘historic’ and ‘local purpose’ reserves.

The Act requires the development of management plans for all reserves except those classified as ‘local purpose’ and ‘government purpose’. Where management plans are available, they outline Council’s general intentions and provide direction on the use, maintenance, protection and development of its reserves.

The creation of reserves is supported by provisions in the RMA and the LGA as follows:

- The **RMA** enables the creation of esplanade reserves and esplanade strips where an allotment of less than 4 ha is created where land is subdivided adjacent to a water body (the sea, a river which has an average width of 3 m or greater, or a lake). The purpose of esplanades is to maintain or enhance the natural functioning of the adjacent water body, and/or enable public access and recreational use. The basic width requirement is 20 m measured from the mean high water springs mark. Applications can be made to waive or reduce the width of esplanades.

- The **LGA** provides for development contribution charges to be made for residential developments to pay for the cost of community and network infrastructure needed to meet the additional demand for growth. This includes stormwater infrastructure and reserve land.

Standards Act 1988 - NZS:4404 Land Development and Subdivision Engineering

While NZS:4404 is a guidance document, it is widely used by territorial authorities and designers for technical compliance of subdivision and land development where these activities are subject to the RMA.

Use of the standard often required compliance with the minimum specific standard as opposed to providing guidance for alternative design approaches. The standard was recently updated in 2010 to encourage sustainable and innovative LID approaches, which should improve the potential for WSD approaches to demonstrate compliance.

Auckland Council publishes design standards as codes of practice, which include a section on stormwater management and form part of NZS:4404.

Land Transport Management Act 2003 (LTMA)

New or revised policies prepared under the LTMA reflect a more integrated approach to transport and land use planning for more sustainable outcomes. The common theme of transport-related documents is to achieve "an affordable, integrated, safe, responsive, and sustainable land transport system".

The national land transport strategy, prepared under the LTMA, sets clear targets for New Zealand, such as 'environmental sustainability', and identifies clear measures to achieve these targets.

New transport policy has led to changes in government agency and local government funding and priorities for transport projects. These changes have implications for the development community by making certain locations more desirable for development due to investment in transport infrastructure. The LTMA is concerned about integrated land use development, i.e. the coordinated development of transport infrastructure and land use development. This approach aligns well with The Auckland Plan where areas for new development are identified partly based on the availability of transport infrastructure.

Under the LTMA, urban design and environmental enhancement are given weighting within the design approval framework, providing potential for consideration of WSD as an approach to stormwater management, and improving the quality of design and environmental outcomes.

Codes of Practice (CoP), Auckland Design Manual (ADM)

Auckland Council, Watercare and Auckland Transport have codes of practice for engineering design for infrastructure. These codes set minimum standards and are used by Council staff for engineering approval. Similarly the ADM provides guidance for urban design and should be used in conjunction with GD04 to maximise design outcomes for Auckland.

A7.0 Land development process

This guideline parallels the land development process, from Site Assessment through to Concept Design phases, focusing specifically on the issues and objectives relevant to WSD. There are other guideline documents that provide further guidance on detailed design phases, such as the Auckland Design Manual, and Auckland Council's codes of practice and technical design guides.

Throughout the land development process, there are several stages where approval is required from Auckland Council (Figure 2). In general all development projects involving the construction of new public assets will require a resource consent, engineering approval and code of compliance. If the concept design does not follow the conditions of existing plans, a plan change application is required, which should include a stormwater management plan highlighting the use of WSD in the concept design. Building consents are also required for most construction activities on private property and some construction activities on public property. Where development (or related activities) might occur on existing parks and reserve land, land owner approval is required.

NZS4404:2010 is the standard document relating to design phases, and NZS3915:2005 is the standard document relating to construction documentation.

A series of checklists are available from http://www.aucklanddesignmanual.co.nz/design-thinking/wsd. They link the principles and stages described in this document with the requirements for consents under both the Local Government Act 2002 (LGA) and the Resource Management Act 1991 (RMA).

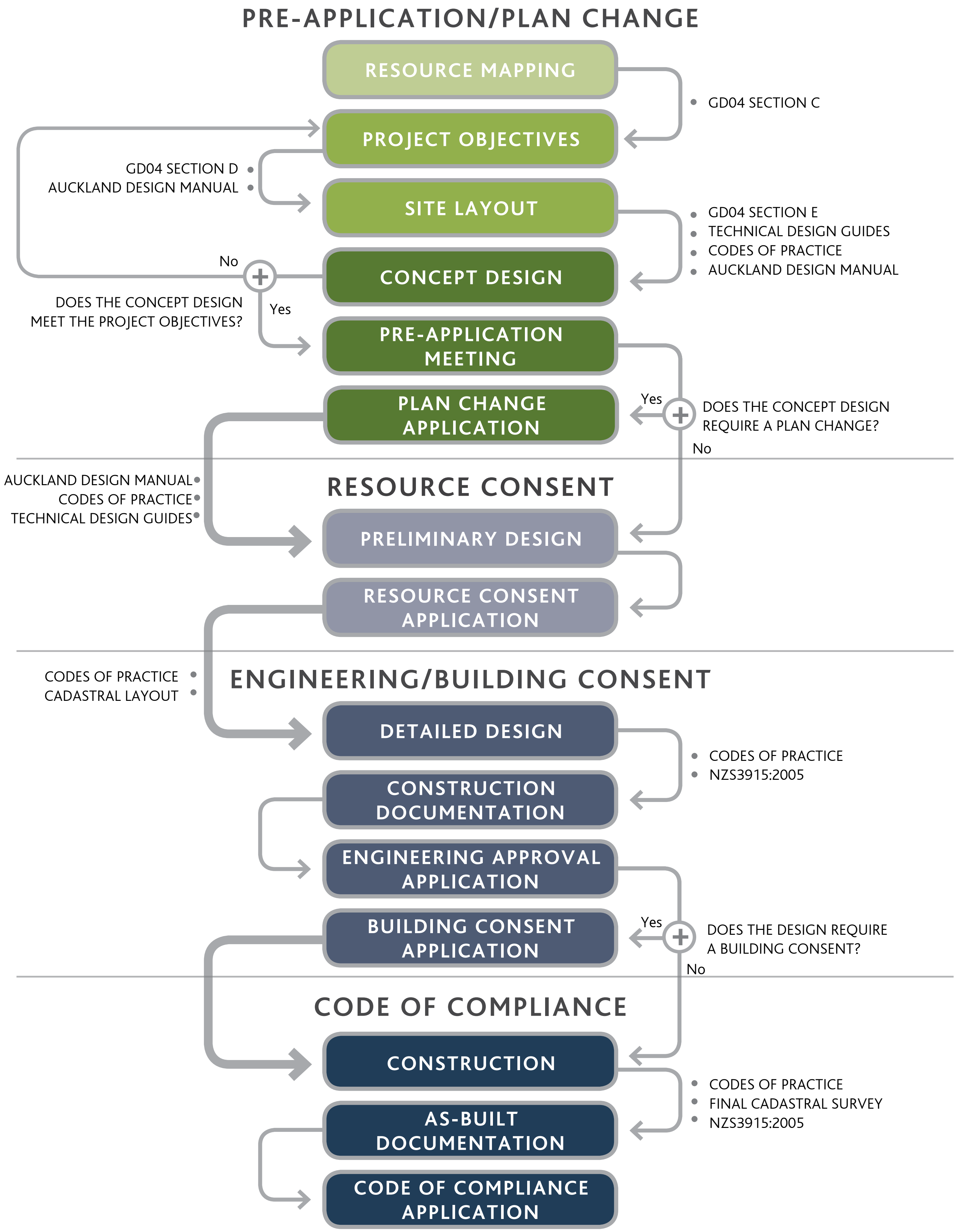


Figure 2: Project stages and regulatory checks required for development

A7.1 WSD concept design

Figure 3 is a flow chart indicating the detailed steps required for the Site Assessment, Site Analysis and Concept Design phases shown in Figure 2. At each step of the process, information requirements and relevant sections of GD04 are identified to assist the designer in the concept development.

The sections in this guideline relate to each of the phases shown in Figure 3. The Site Assessment phase (Section C) involves capturing all the information required up front for the project to provide for a 'no surprises' approach to Site Analysis and Concept Design.

The Site Analysis phase (Section D) takes the resource map completed in the Site Assessment phase and applies environmental and development frameworks to determine the most appropriate development layout and form.

The Concept Design phase (Section E) takes the development form and adds sufficient detail to ensure the design is feasible and to allow the preparation of an initial cost estimate. The concept design should provide a sufficient level of detail for plan change applications if required.

Note: Technical design guide documents provide detailed advice for design and construction of devices.

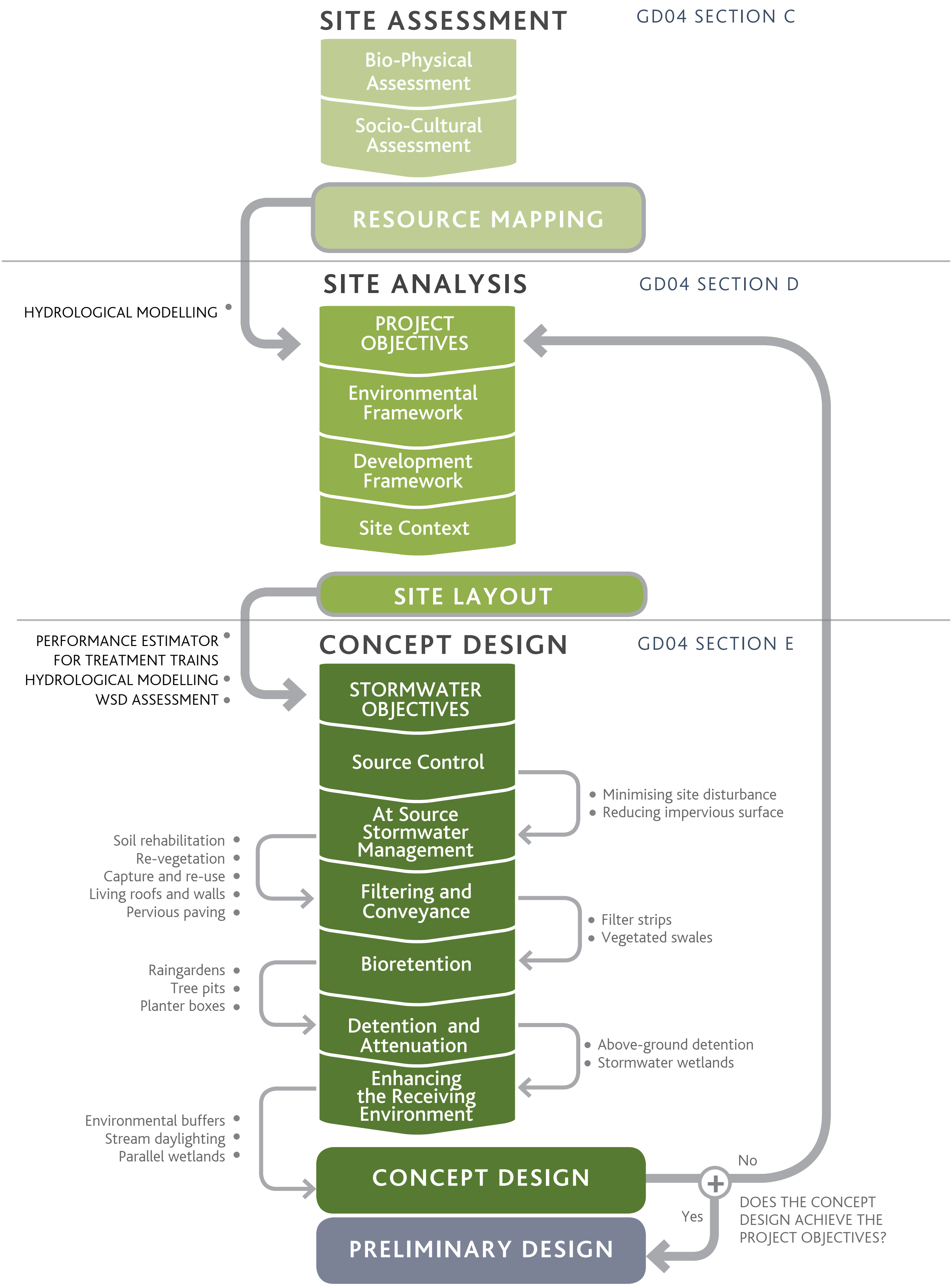


Figure 3: Project design phases discussed in this guideline

Bayside Reserve, Browns Bay, Auckland

A8.0 Project team

To deliver development objectives and manage project risk, design should be carried out by suitably qualified and experienced professionals who can interpret site conditions and direct a suitable WSD response.

Project teams vary according to the scale and complexity of a project. Regulatory authorities may be part of a working group where appropriate in order to achieve buy-in throughout the design process, expedite consenting timeframes, and determine the appropriate level of detail required for consenting documentation. In general, a project team could include the following expertise:

- Planning, project management and legal advisers
- Specialist advisers (depending on the site attributes) including arborists, environmental scientists, terrestrial and freshwater ecologists, transport planners and geomorphologists
- Designers (with particular regard to landscape architects, engineers, architects, and urban designers). There may also be benefit in having specialist expertise in WSD approaches.
- Engagement specialists, social scientists and installation artists as appropriate
- Building partners
- Regulatory authorities.

WSD promotes an inter-disciplinary and collaborative design approach to recognise inherent project risks, identify efficiencies for the design and construction programme, and provide for multiple beneficial outcomes for the project and the developer's investment. Continuity of the project team through the design phases provides for the most informed decision-making, and will avoid potential misinterpretation and costly reiterations.

SECTION B: OBJECTIVES AND SOLUTIONS

The Waterfront, Seatoun, Wellington

B1.0 Objectives

Water sensitive design (WSD) is an inter-disciplinary approach to urban planning and development which provides opportunities for integration of land use and freshwater management and aims to protect and enhance natural freshwater systems, by sustainably managing water resources and mimicking natural processes. This approach will contribute to the enhancement of ecosystems and will maximise long-term environmental, social, cultural and economic outcomes for Auckland communities.

The objectives for WSD for stormwater aim to deliver the priorities identified in The Auckland Plan. Relevant priorities in The Auckland Plan are:

Strategic Direction	Priority
7 Auckland's Environment	1 Value our natural heritage 2 Sustainably manage natural resources 3 Treasure our coastline, harbours, islands and marine areas
10 Urban Auckland	1 Realise quality, compact urban environments 2 Demand good design in all development
12 Auckland's Physical & Social Infrastructure	1 Optimise, integrate and align network provision and planning 2 Protect, enable, align, integrate and provide social and community infrastructure for present and future generations

Based on these priorities, a set of objectives has been developed for WSD. The objectives listed below are intended to be aspirational at the regional and catchment scale and achievable at the site scale. Note that a definition of WSD is given in the PAUP and included in Section A2.0 of this document.

Each of these objectives aims to deliver on the priorities for Auckland identified in The Auckland Plan:

- Reduce stormwater runoff - reduce stormwater runoff volume and peak flow to predevelopment levels
- Manage stormwater quality - manage stormwater quality to avoid adverse environmental effects
- Minimise soil disturbance - minimise sediment in stormwater runoff, especially during construction, and protect site soil resources from modification
- Promote ecosystem health - promote the health of regional ecosystems and their associated environmental services through the management of stormwater at the catchment and site scale
- Deliver best practice - deliver best practice urban design and broader community outcomes as part of stormwater management delivery
- Maximise return on investment - achieve maximum value from stormwater management through the consideration of a broad range of benefits.

The following sections provide further detail on each objective and the solutions available to achieve these objectives.

B2.0 Reduce stormwater runoff

B2.1 The WSD 'water cycle'

The water cycle (also known as the hydrological cycle) describes the various states of water as it moves through the environment - falling as rainwater, infiltrating to groundwater, moving toward streams, evaporating to cloud systems, and so on. As it moves through the environment, water interacts with natural systems. Trees intercept rainfall, soil and humus layers attenuate stormwater runoff and infiltrate it to ground, and terrestrial and aquatic vegetation captures and transpires water back to the atmosphere (Figure 4).

Land development disturbs these natural processes through vegetation clearance and soil modification. The developed site, with impervious surfaces and kerb and pipe systems, tends to bypass natural systems and direct large stormwater volumes to lower catchment areas, resulting in flooding and potentially damaging effects to natural stream and wetland environments (Figure 5).

A WSD approach to development protects and enhances existing 'natural' processes in the catchment. Where impervious surfaces do occur, stormwater runoff is directed to vegetated landscapes and devices such as raingardens and swales, which mimic 'natural' processes through enhanced infiltration, transpiration and attenuation in floodplains (Figure 6).

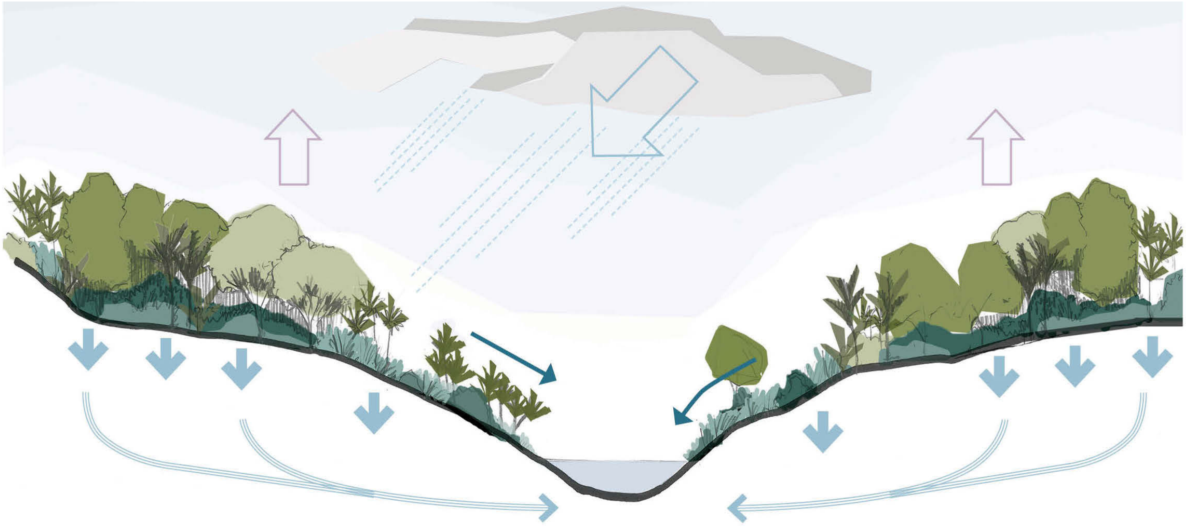


Figure 4: The water cycle interacts with plant and soil systems that capture, infiltrate and transpire rainwater and stormwater runoff.

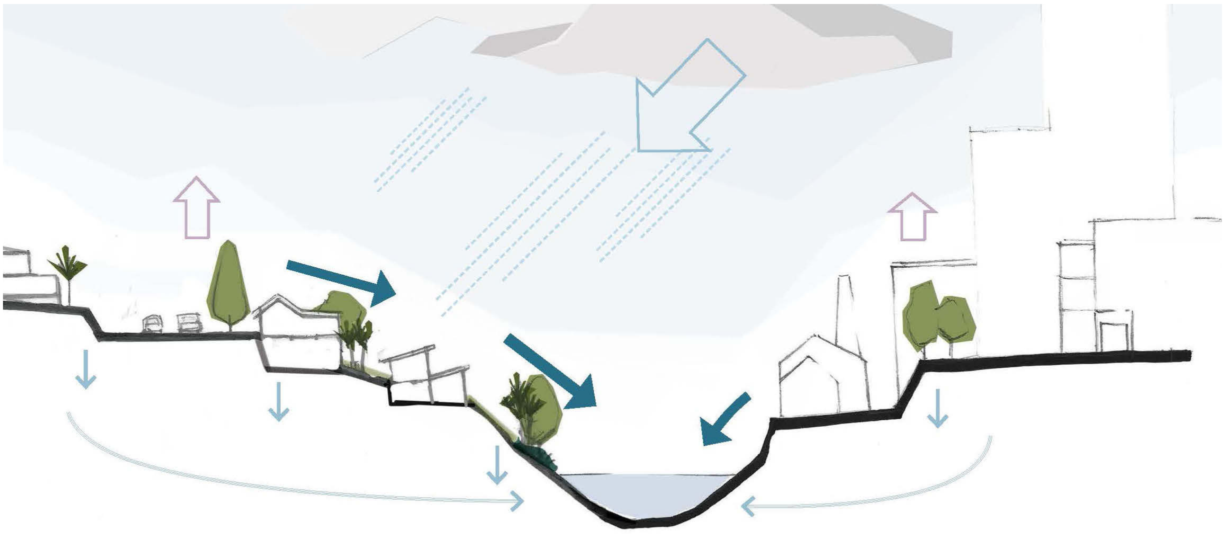


Figure 5: A developed catchment has increased overland and reticulated flows directed rapidly to receiving environments, bypassing natural systems and processes.

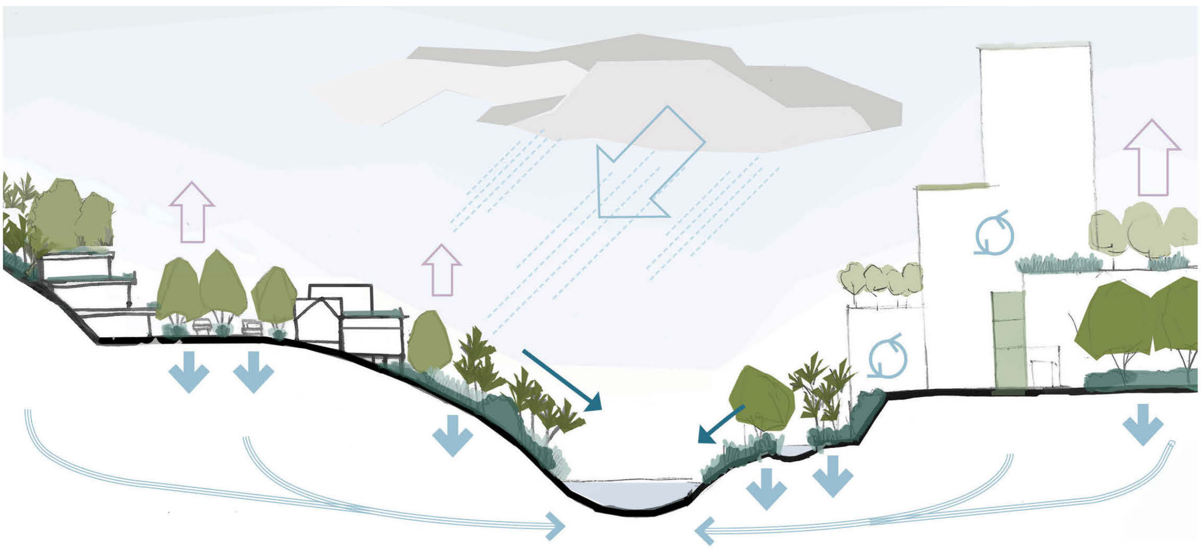


Figure 6: A WSD approach protects natural systems and directs runoff to landscape areas that have been designed to utilise natural processes to treat and retain runoff.

KEY:

precipitation evapotranspiration shallow infiltration deep infiltration surface runoff

B2.2 Moderating peak flow rates of stormwater runoff

In many conventional urban developments, stormwater collects on impervious surfaces before 'running off' to kerbs, catchpits and pipes. Based on international literature, a catchment containing 10-20% impervious surface will generally experience a two-fold increase in stormwater runoff volumes during a storm event; a 35-50% increase in impervious area will experience a three-fold increase in stormwater runoff; and a 75%+ area, a fivefold increase (Paul & Meyer, 2001).

Figure 7 is a hydrograph illustrating the discharge of stormwater quantity over time. The developed situation assumes stormwater runoff rapidly coalesces on impervious surfaces, realising a higher peak flow.

This increased runoff rapidly concentrates at the bottom of the catchment via piped systems, leading to significantly larger peak flows. Apart from immediate concerns from surface flooding, there can be serious consequences when these flows reach streams, wetlands or estuaries (receiving environments), where they can cause increased erosion, bank slumping and the subsequent deposition of transported sediments in low-energy downstream environments.

Rainfall infiltration is important to sustain vegetation and groundwater flows to stream environments during dry periods. Impervious surfaces and piped networks reduce the ability of rainfall to infiltrate to groundwater.

Stormwater ponds have traditionally been used to manage these increased flows. They capture and hold stormwater runoff at the bottom of a catchment and provide for a controlled discharge rate to the receiving environment. The hydrograph in Figure 8 illustrates a scenario where a pond is used at the bottom of the catchment, showing the same quantity of stormwater released over a longer time period.

Ponds generally require large areas of flat land that would otherwise be available for development or open space reserve. WSD looks at alternatives to ponds by directing runoff from impervious surfaces to many and dispersed stormwater devices or purpose-designed landscape areas such as vegetated swales, raingardens and pervious paving.

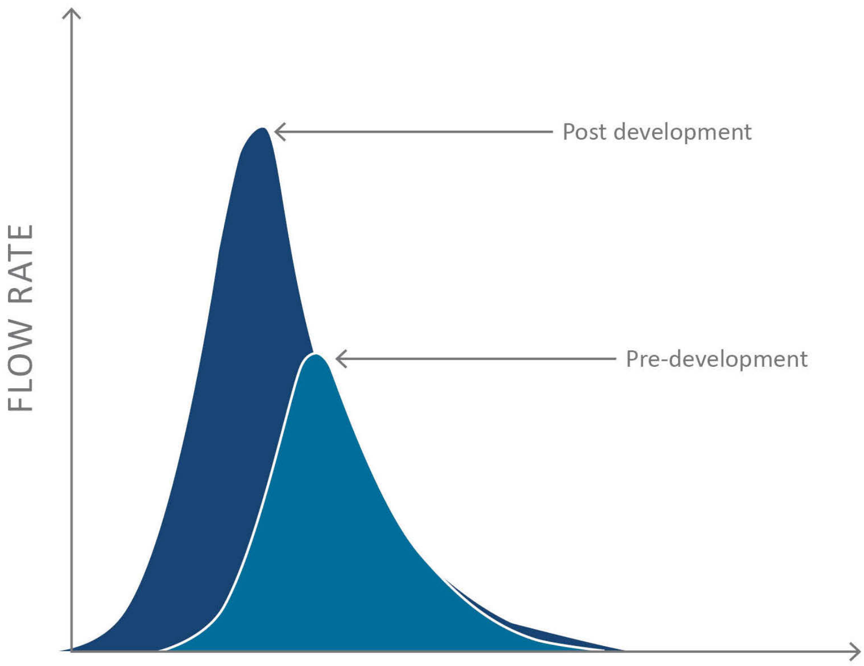


Figure 7: Example pre & post-development hydrographs for uncontrolled conditions (adapted from Shaver, 2000)

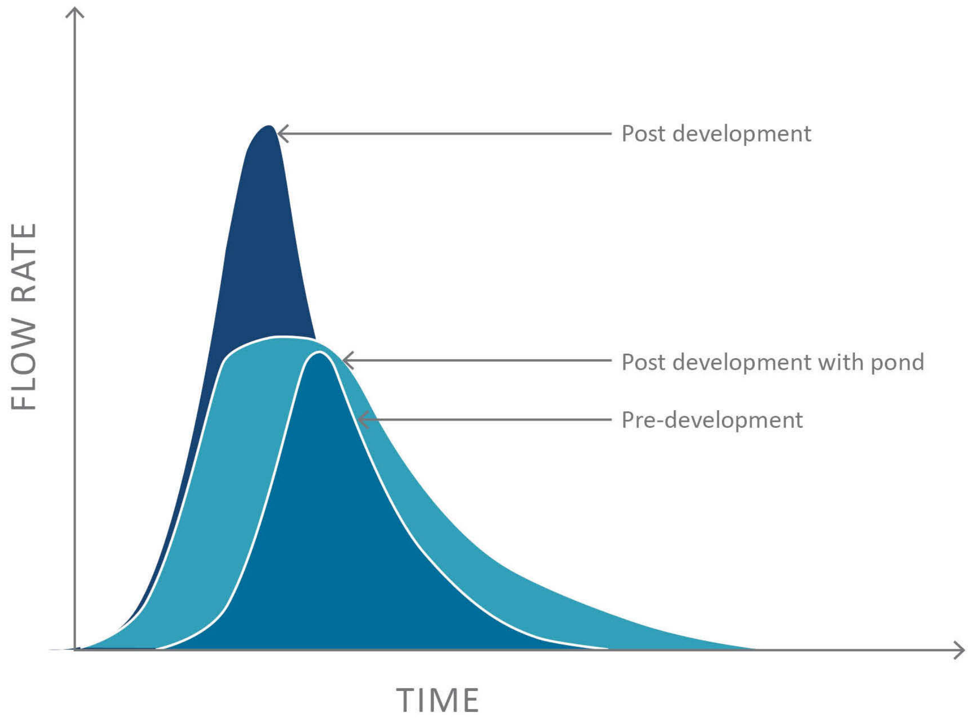


Figure 8: Typical post-development hydrograph with detention (adapted from Shaver, 2000)

B2.3 Reducing total volume of stormwater runoff

As shown in Figure 8, even though ponds control the discharge rate, there is still an increased total volume of water entering the receiving environment over a longer time period. The total stormwater volume discharged from the pond is represented in a hydrograph as the area under the graph.

A larger total volume of stormwater effectively results in increased hydraulic ‘work’ on the receiving environment, especially when a large storm event leads to a prolonged peak flow period. In addition, where there are multiple ponds in a single catchment, the extended period of peak flows can overlap, leading to a greater overall peak flow in the receiving environment. This coincidence of prolonged peak flows can lead to flooding in the lower catchment and potentially extend the time that a stream is exposed to erosive flow. The hydrograph in Figure 9 illustrates this situation, known as superposition of peak flows.

Auckland Council has developed design requirements in the PAUP that require stormwater management devices to provide a specific detention and retention volume in some catchments. Detention reduces peak flows by capturing and attenuating stormwater volumes and controlling the discharge rate. Retention reduces flow volumes discharged directly to streams by capturing flows and allowing them to infiltrate to ground or to be re-used for non-potable supply. These detention and retention recommendations are based on ‘continuous simulation’ and ensure that devices are targeted at mitigating a range of storm intensities and volumes. For further information on the PAUP rules, please refer to Auckland Council Technical Report TR2013/035 *Auckland Unitary Plan Stormwater Management Provisions: Technical Basis of Contaminant and Volume Management Requirements*.

Climate change resilience is also considered. Details on climate change requirements for design are in the Auckland Council Stormwater Code of Practice (AC Stormwater CoP, 2013).

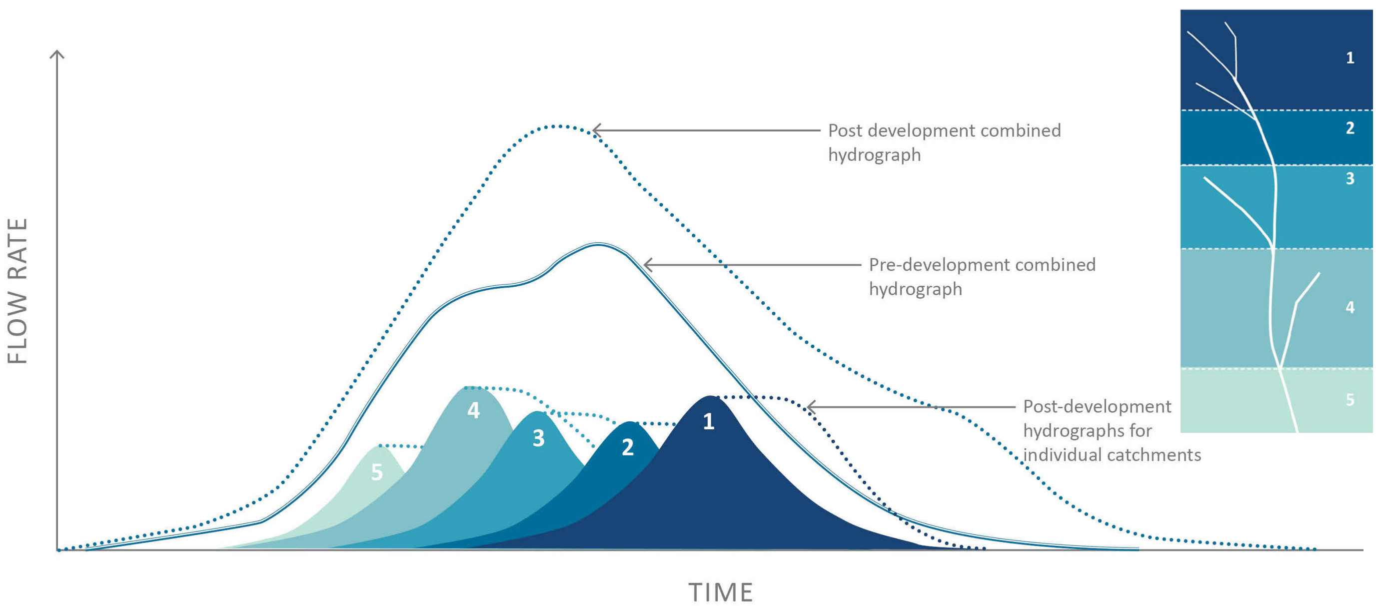


Figure 9: Superposition of peak flows from multiple catchments with extended detention (adapted from Shaver, 2000)

A WSD approach reduces the risks associated with storm variations and weather anomalies by limiting the generation of stormwater runoff at its source, and providing opportunities for stormwater retention in multiple smaller catchments. Ways to reduce stormwater runoff using WSD approaches include:

- Retaining mature (or planting new) tree canopy to intercept and transpire rainfall
- Protecting and remediating porous soils to improve groundwater infiltration
- Reducing impervious surfaces through site and infrastructure layout
- Retaining or reinstating natural drainage systems to slow and detain stormwater flows
- Increasing pervious surfaces through pervious paving, living roofs, etc.
- Disconnecting stormwater from piped networks and redirecting this runoff to landscaped areas and WSD devices (swales, raingardens, etc).

All of these approaches are discussed in this guideline document in Sections C to E, including the means to optimise their effectiveness through combined application.

B2.4 Reducing surface flooding

The AC Stormwater CoP requires that the primary conveyance network conveys 10 year Average Recurrence Interval (ARI) flows and that a secondary overland flow path is provided to convey the 100 year ARI event safely in compliance with the PAUP.

Part of the WSD approach is to maintain the flow and storage capacity of natural drainage systems such as streams, headwater channels and natural floodplains. These stream systems attenuate surface flows and extend detention periods compared with pipe networks, reducing (but not eliminating) flooding effects. However as part of developing an urban environment, these drainage systems must be appropriately buffered from the hydrological changes occurring in their contributing catchment. Buffering techniques are discussed in Section D.

Docklands, Melbourne, Australia

B3.0 Manage stormwater quality

Aquatic ecosystems are very sensitive to water quality changes as a result of stormwater runoff. This has been observed in the direct effects of toxic pollutants, the effects of combinations of different contaminants, and the accumulation of persistent chemicals within animal food webs (Hauer & Hill, 1996). Stormwater runoff can contain elevated levels of nutrients, metals, pesticides, temperature and organic contaminants (Paul & Meyer, 2001). The PAUP identifies sediment, metals and temperature as key contaminants to be managed in the urban environment. Potential contaminant sources are discussed in further detail in Section E in relation to 'treatment train' responses.

The previous approach to water quality treatment in Auckland has been to require the capture and treatment of stormwater runoff from 80% of all storms. A treatment pond is a common stormwater device which generally utilises the process of sedimentation to capture contaminants. Sedimentation assumes granular material in suspension will 'drop out' to the bottom of the pond and embed the contaminants that are bound to them. This process can be enhanced through physical filtration and biological uptake (wetland planting) or flocculation (through chemical additives).

High flows can re-suspend sediments in ponds, and runoff temperatures can increase dramatically during periods of low flow. Ponds are also limited in their ability to settle silts and clay particles and remove dissolved contaminants from solution.

A WSD approach avoids potential sources of contaminants (impervious surfaces and exposed hazardous materials) and additionally promotes the treatment of stormwater runoff close to source. Examples of WSD approaches to water quality treatment include:

- Minimising the use of materials that leach contaminants such as copper, galvanised metal and treated timber
- Applying appropriate land management practices for fertiliser and pesticide application to minimise effects of harmful substances on stormwater systems
- Maximising landscape elements such as trees to capture and metabolise airborne and waterborne pollutants and to provide shade to reduce thermal effects
- Reducing the extent of impervious surfaces to limit areas where contaminants can accumulate
- Where impervious surfaces do occur, directing surface runoff to landscape areas to allow the 'first flush' to achieve some preliminary level of treatment
- Creating permeable surfaces (pervious paving, living roofs, etc.) to infiltrate stormwater and capture dissolved contaminants
- Integrating treatment devices such as raingardens, swales and wetlands, which utilise natural microbial activity at the plant-water-soil interface to transform and take up contaminants.

B4.0 Minimise soil disturbance

Large areas of the Auckland region are underlain by Waitemata complex soils in which fine clays are dominant. Many of these soils are highly vulnerable to degradation (compaction and loss of soil structure), difficult to rehabilitate over large areas, and take many years to recover naturally. These fine clays are susceptible to erosion and can be carried in stormwater runoff until they reach estuarine and wetland environments, where deposition of sediment frequently occurs.

Small pockets (generally <1 ha) of soil with higher permeability and moisture storage potential can be found within the areas of fine clays. These pockets are primarily found on gentle slopes, broad ridges and terraces. Much of the Auckland region is underlain by granular soils and basalt rock, which can also have good infiltration properties.

The key to managing soil resources for stormwater management in Auckland is to:

- Identify soil properties and their extents through soil surveys
- Limit the development footprint and extent of soil disturbance and erosion where practical
- Provide for a development layout that considers vulnerable soils, steep slopes, overland flow paths, riparian margins, spring seepages and aquifer recharge
- Minimise the degradation and compaction of site soils, and apply appropriate sediment and erosion controls during construction to reduce sediment runoff
- Remediate soils where practical to optimise their beneficial properties
- Consider alternative land development approaches, other than the traditional ‘cut-to-fill’ operations, for site levelling.

Management of healthy soils for stormwater management is discussed in more detail in the Auckland Regional Council Technical Report TR2009/083 *Landscape and Ecology Values within Stormwater Management* (Lewis et al., 2010). The Auckland Regional Council Technical Publication TP90 *Erosion and Sediment Control Guidelines for Land Disturbing Activities in the Auckland Region* (1999) (which will be replaced by the Auckland Council Guideline Document GD2016/005) also sets out principles and methods for erosion and sediment control in conjunction with land disturbance activities.

B5.0 Promote ecosystem health

B5.1 Freshwater environments

The Auckland region supports 21 native fish species (Stevenson & Baker, 2009). Fourteen of these fish are diadromous, undergoing migrations between fresh and saltwater as part of their life cycle. Increased stormwater runoff associated with developed catchments can have a direct physical impact on aquatic environments. This direct physical impact is due to increased volume and contaminants, affecting both the diversity of habitats and the health of fish and aquatic invertebrates that use these areas for some (or all) of their life cycle. Water quality is a significant determinant of species richness in Auckland stream environments (Allibone et al., 2001).

Auckland streams cater for complex life cycle stages of aquatic fauna, both common and rare. Streams, wetlands and estuaries are recognised as highly productive environments for threatened and endangered species (Becker et al., 2001). WSD also promotes vegetated buffers for aquatic environments (streams, wetlands, spring seepages, etc.) from potential land use effects. In addition to assisting with local climatic effects and protection of habitats, these riparian buffers also help to moderate stormwater runoff quality and quantity effects. The riparian zone is the area of land adjacent to streams and wetlands that is the transition between land and water (Becker et al., 2001).

WSD promotes the protection and enhancement of urban streams from the impacts of developing catchments. The benefits of this approach include providing ecosystem services and their associated social, cultural and economic values, and increasing habitat diversity and biodiversity.

WSD methods to promote aquatic ecosystem health include:

- Keeping and enhancing streams and other freshwater environments
- Preserving and restoring riparian vegetation along banks, natural floodplains, wetland margins and the groundwater zones under streams
- Linking areas of riparian vegetation to create riparian corridors.

Promotion of continuous stream corridors

Greenways (also known as lineal parks), wildlife corridors and riverways are lineal open spaces linking natural, cultural and recreational areas in coincidence with streams or other lineal landscape features. Greenways provide the framework to protect, conserve and link natural resources and open spaces. In Auckland, greenways are being used to provide important cycle and walkways.

Continuous stream corridors do not need to comprise entire stream lengths (although this is ideal). ‘Islands’ of continuous habitat along streams also provide meaningful habitat, providing stepping stones for migratory animals, and acting as repositories for ongoing and future recolonisation of species in the catchment. In Auckland, stream corridors are marginal areas for development due to flooding constraints, steep slopes and poor aspect. However, stream corridors do have significant value as open space linkages between coastlines, ridgelines and volcanic cones. They can have diverse and continuous ecologies, and where they are suitably enhanced they can attenuate and treat stormwater runoff.

Some of the mechanisms to promote greenways are:

- Collaboration between landowners and community groups
- Providing greenways when preparing master and structure plans
- Auckland Transport and Local Boards partnering on the Greenways Project.

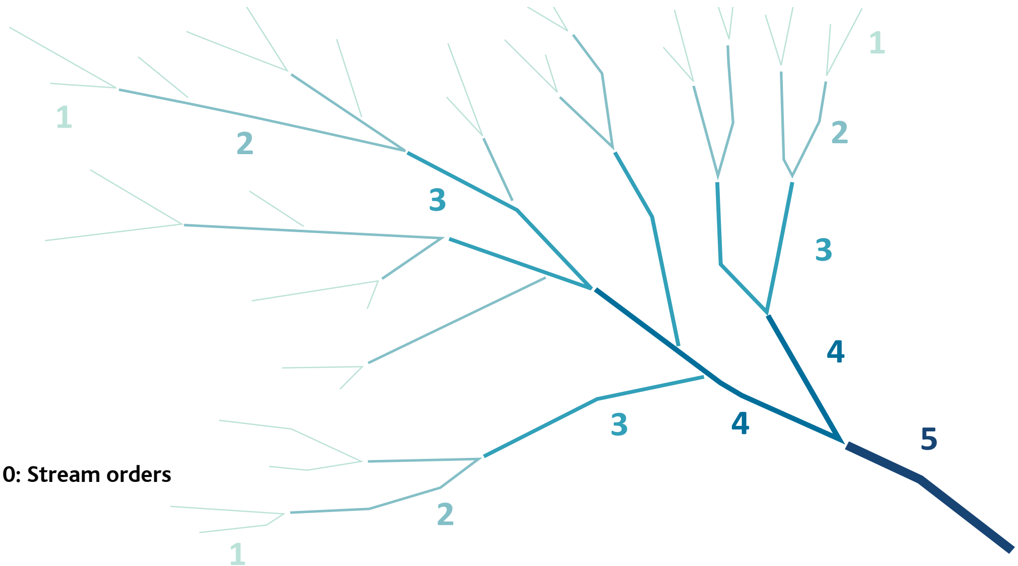


Figure 10: Stream orders

Headwater streams

In total length, almost 70% of Auckland watercourses are first order (or headwater) streams. When combined with second order streams, that percentage increases to almost 90% (O'Brien, 1999). Second order streams are those formed by the junction of two first order streams; a third order stream is formed by the junction of two second order streams, and so on (Figure 10).

Headwaters can include isolated pools, spring seepages, wetlands, and ephemeral and intermittent streams. These often support invertebrate taxa not otherwise present in permanent streams (Parkyn et al., 2006). These headwater areas also sustain downstream habitats through nutrient and carbon inputs, insect drop, flow moderation, and by through their contribution to base flows.

The large number and small size of headwater streams make them vulnerable to modification from land use change and development. It has been common for ephemeral and intermittent streams to be piped or filled as part of development. This large scale modification and culverting of smaller headwater streams throughout Auckland represents a significant risk to freshwater ecology, and the loss of these systems could have a dramatic effect on larger order watercourses downstream. When considering aquatic resource protection, it is important to consider the entire catchment and to recognise that all streams regardless of size are integral components of a catchment system. More information on Auckland's headwater streams can be found in ARC Technical Publications 310-313 *Small Headwater Streams of the Auckland Region* (2006).

WSD methods to maintain headwater streams include:

- Planning the road network to work with the stream network, minimising crossings and the need for culverts
- Identifying intermittent and permanent streams at the project onset, and preserving a buffer around them in the development layout
- Planting around intermittent and permanent streams.

Wetland environments

Wetlands are permanently or intermittently wet areas, shallow water and land-water margins that support a natural ecosystem of plants and animals adapted to wet conditions (RMA 1991, s2.1). Wetlands can take the form of spring seepages, swamp forest, bogs, fens, marshes or floating rafts. All of these diverse wetland types can be constructed and/or restored to provide for the values that wetlands contribute.

Wetlands provide for highly diverse species assemblages and they perform a very important role in the catchment by providing water quality treatment at the plant-soil-water interface, and by attenuating peak flows. WSD strongly promotes the restoration of natural wetlands for their inherent stormwater management processes. The application of wetlands to stormwater management is discussed in further detail in Section E.

B5.2 Coastal environments

Coastlines are at the interface of freshwater, marine and terrestrial environments, providing diverse community assemblages and unique coastal and marine habitats. Estuaries are nurseries for freshwater and marine fish, encouraging a very diverse food web, including migratory birds.

Stormwater discharge is a recognised threat to marine environments, with high contaminant build-up common near stormwater outfalls (Norkko et al., 2002). Sediment delivered in stormwater accumulates in estuaries due to flocculation in saline conditions and settling out in low energy environments. Large quantities of sediment can smother shellfish beds, seaweeds and other marine communities, with a subsequent impact on marine food webs. Contaminants such as heavy metals and polycyclic aromatic hydrocarbons (PAHs) can bio-accumulate in the tissues of marine organisms such as shellfish, creating potential health issues for marine life and people who eat them. Environmental monitoring by Auckland Council has identified increasing contaminants such as zinc and copper in our estuaries (Timperley et al., 2004/2005).

Being at the bottom of a catchment, coastal areas often have issues with infrastructure capacity, which can result in combined sewer overflows (CSOs) in catchments with combined networks. CSOs are a common cause of poor water quality in streams and beach closures (due to microbiological reasons), and can lead to algal blooms from excess nutrients in these environments. Coastal development can impact directly on coastal environments through non-point source pollution, stormwater outlets and septic wastewater treatment systems. Coastal environments are also exposed to natural hazards such as flood and coastal inundation, wind erosion and land instability, which can compromise the function of stormwater systems and erode stormwater outlets.

WSD protects lower catchment environments through contaminant removal close to the source in the contributing catchment. WSD seeks to reduce stormwater flow peaks which in turn reduces stress on stormwater system capacity and minimises CSOs in catchments with combined networks. WSD also aims to protect and enhance the natural systems that give coastal systems their resilience with comprehensive regional management of flooding and natural floodplains.

B5.3 Biodiversity

The New Zealand Biodiversity Strategy (Ministry for the Environment [MfE], 2000) defines biological diversity (biodiversity) as "the variability among living organisms ... and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems" (Quality Planning, 2010).

New Zealand has a significant number of endemic species which are vulnerable to habitat modification. WSD promotes native habitat and self-regulating ecosystems, and promotes the exclusion of invasive species through integrated pest management. This includes the selection of robust plant species, allowing for natural succession processes and promoting effective buffer zones to prevent pest incursions.

Broad specifications for plant and animal pest control is presented in the Auckland Regional Council Technical Report TR2009/083 *Landscape and Ecology Values within Stormwater Management* (Lewis et al., 2010). Further information on control methods is available from the Council Biosecurity team, and the means to promote ecosystem diversity and connectivity is discussed in Section D.

B6.0 Deliver best practice

WSD has been adopted by a broad range of professional disciplines in New Zealand, and frequently acts as the catalyst for inter-disciplinary design in land development. WSD promotes multiple objectives for stormwater management, including incorporating iwi perspectives as appropriate, enhancing landscape and natural character values, providing for positive urban design outcomes and ensuring public safety.

B6.1 Matauranga Maori

Matauranga Maori refers to the body of knowledge that Maori communities and individuals have accumulated in the time that Maori have lived in Aotearoa. This knowledge is place-focused, and based on empirical observation and interaction with environments in which Maori traditionally occupied and continue to live.

A definition is provided by Te Ahukaramü Charles Royal:

> **"Matauranga Maori, or Maori knowledge, is created by Maori humans according to a set of key ideas and by the employment of certain methodologies to explain the Maori experience of the world"** (Royal, 1998).

Matauranga Maori is a living resource, and able to develop and grow in response to the changing world that contemporary Maori live within, and to which this knowledge must be applied. Another key aspect of matauranga Maori is that the holders of this knowledge are tangata whenua, and access to this detailed knowledge relies entirely upon consultation and engagement with these groups.

Traditional values and concepts derived from matauranga Maori are valuable management tools from design/construction to monitoring, and for policy and planning perspectives. There is considerable potential within the design of stormwater management systems to acknowledge and include matauranga Maori including plant varieties for cultural harvest, kaitiakitanga (stewardship), and promotion of mauri (life force/spiritual health).

Mauri

The concept of mauri is a central belief of Te Ao Maori, the Maori world, with connections to the spiritual, physical and temporal realms. Loosely translated as the life force or life essence which exists within all matter, mauri sits at the very core of sustainable design for Maori. Mauri levels are potentially erodible through poor environmental management. However, restoration of mauri is also achievable through the application of appropriate decision-making and management practices.

A community, environment, or resource possesses its own mauri, which is the aggregation and inter-connectedness of the mauri of its constituent components. If one aspect of the community, environment or resource is degraded, the mauri of the total entity is affected and degraded, and the quality of life of that community will suffer. If that deficient aspect is restored, then the mauri of the total entity is restored.

In this way, the mauri of resources should be preserved through inspection and maintenance of WSD practices to keep a state of balance, being an indicator of strength, good health, and resilience of our communities. It is very important tangata whenua are involved in environmental decision making and planning processes to minimise potential effects on mauri, Maori values, and Maori communities.

Wai

Wai (water) is one of the central components of the spiritual and physical worlds for Maori. It is a gift that permits, sustains and promotes life and well-being for all. Knowledge of water cycles is an important aspect of matauranga Maori, and is held and administered by tangata whenua within their areas of influence.

Water can be described in at least five determinable states for Maori, all of which relate to the concept of mauri and the presence of mauri within that water:

- 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 polluted or dangerous for humans)
- Waitai (seawater, the surf or the tide).

Within a water cycle, mauri is very high within rainfall, but is progressively reduced as it flows over impervious surfaces, contacting and transporting heavy metals, pesticides, fertilisers, pathogens and other potential pollutants within the environment. This degradation of water quality will affect the mauri of receiving waters into which it is discharged. Thus, discharging stormwater directly into water with higher mauri is an example of unnatural mixing of mauri, and should be avoided. Conversely, the dispersal of stormwater to/through land-based systems will restore the mauri of that water, and is seen by many Maori as the most appropriate means of stormwater management.

Appropriate management practices

Potential management practices that account for tangata whenua perspectives may include:

- Recognition and involvement of tangata whenua in decision-making and planning processes as kaitiaki (guardian)
- An increased level of meaningful engagement around stormwater management practices and landscape responses
- Engagement of matauranga Maori in research and design of water systems
- Avoiding the mixing of waters from different catchment sources
- Treating stormwater by passing it through land or rock before it is released into receiving environments
- Water conservation, including water harvesting, to preserve the resource and its mauri
- Identification, recognition and appropriate protection/enhancement of culturally significant sites/features
- Re-vegetation for stormwater management utilising indigenous plants, and incorporating species that will allow Maori to safely harvest traditional flora and fauna resources
- Tertiary treatment wetlands with the potential for use by communities
- Protecting and restoring streams as taonga (socially or culturally valuable resources), including restoring eroded and channelised streams and daylighting streams from pipes.

B6.2 WSD and urban design

WSD is provided as a tool to assist Auckland's transformation to a water sensitive city. To accomplish this, WSD must integrate with urban design best practices (discussed below) to balance natural and built environments and achieve a 'liveable' city.

The New Zealand Urban Design Protocol (2005) is a central government initiative to improve the quality of the urban environment. Signatories to the Protocol include central and local government agencies, developers and design professionals. The urban design discipline involves all aspects of towns and cities, ranging in scale from region to towns, individual streets, public spaces and buildings. Urban design looks at the environmental, economic and socio-cultural consequence of design decisions (MfE, 2005). The MfE sets out seven essential urban design qualities, known as the '7 Cs':

Context - The contribution individual buildings, places and spaces make to towns and cities

Character - Enhancing distinctive character, heritage and identity for urban environments

Choice - Ensuring diversity and choice for people

Connections - Enhancing a variety of networks to link people together

Creativity - Encouraging innovative and imaginative solutions

Custodianship - Ensuring design is environmentally sustainable, safe and healthy

Collaboration - Sharing knowledge across sectors, professions and with communities.

There is significant crossover between WSD and urban design principles, including the following aspects:

- Both practices foster inter-disciplinary approaches and integrated design processes.
- WSD promotes clustering or intensification of built form to protect ecosystem resources at the catchment and regional scale. Urban design seeks the same outcome to accommodate transit and mixed use centres.
- Both practices support design innovation.
- Sustainability is a guiding paradigm for both practices to provide for future generations and to optimise a city's resource base.
- WSD and urban design favour flexible regulatory provisions for land use planning.
- Both support community forms that are less dependent on automobiles for connectivity.

There is a perceived conflict between urban design, which promotes dense urban form to achieve an activated and connected community, and WSD, which promotes greater open space and the preservation of natural drainage patterns. These are not necessarily divergent views at larger planning scales (i.e. the catchment or region), where both practices seek to intensify development within appropriate areas (i.e. transit-oriented centres), while preserving a supporting environmental framework in other more sensitive or valuable environments.

Auckland has a challenge to respond to significant growth pressures (predictions account for the population doubling in the next 20-30 years), while achieving a 'liveable' city environment. In combination, urban design and WSD will support the region's future growth and development by promoting appropriate urban form with protected and enhanced natural freshwater systems.

Wynyard Quarter, Auckland

B6.3 Landscape and natural character values

Landscape values

The enhancement of landscape values is a significant driver for WSD approaches. This is discussed in some detail in the Auckland Regional Council Technical Report TR2009/083 *Landscape and Ecology Values within Stormwater Management* (Lewis et al., 2010).

The New Zealand Institute of Landscape Architects (2010) identifies the following attributes that make up our landscapes:

1. Biophysical elements, patterns and processes
2. Sensory qualities
3. Spiritual, cultural and social associative activities and meanings.

The rich complexity of landscape attributes, their relationships, and diverse cultural perspectives can be difficult to accommodate in land use change. The landscape architecture profession is uniquely placed to assist by recognising the values and attributes of landscape, by managing these for resilience, and by ensuring that they contribute to an ongoing sense of place for a community.

The public is acutely aware of the effects of landscape change on our natural systems. Where natural systems and processes are retained or enhanced in a landscape, there is the perception of sensitivity and stewardship for the local environment. These natural environments provide a range of services that benefit people directly or indirectly, for example as rejuvenating and meditative spaces, becoming important refuges from urban stressors.

Natural character values

Natural character values are recognised under the RMA Matters of National Importance (Part 2 Section 6) in relation to managing the use, development and protection of natural and physical resources. WSD approaches are complementary to the purpose and principles of the RMA by promoting the protection of the natural character values of wetlands, lakes, rivers and their margins from inappropriate subdivision use and development.

A study on natural character, entitled *Environmental Performance Indicators* (MfE, 2002), describes ‘naturalness’ as the extent to which natural elements, patterns and processes occur. WSD approaches promote the protection and enhancement of natural character values, particularly for indigenous vegetation and habitats of indigenous fauna and flora, natural drainage patterns, watercourses, wetlands and coastal environments.

B6.4 Public safety

WSD promotes the public use of open spaces associated with streams and wetlands, which can lead to increased public awareness for the values of these systems. When designing for public use, it is important to balance public safety with the benefits of fully experiencing these environments.

Crime prevention

Designers of stormwater management areas that provide for public access require a working knowledge of the Ministry of Justice's (MoJ) guidelines for crime prevention through environmental design (CPTED). The guidelines include the following principles (MoJ, 2005):

1. Access – unencumbered access and movement choices to avoid potential criminal activity
2. Surveillance and sight lines – appropriate planting and access layout for clear visibility
3. Layout – clear and logical orientation within a site
4. Activity mix – 'eyes on the street' through encouraging access and use of a site
5. Sense of ownership – a level of amenity that suggests and promotes community care
6. Quality environments – well designed and maintained open spaces and stormwater facilities
7. Physical protection – to encourage active use of appropriate areas only.

Community 'ownership' and vigilance can be encouraged through dedicated public access, community gathering areas, and through creating passive surveillance from adjacent homes. A community can also be consulted when stormwater management areas are being designed, and/or be invited to participate in the implementation of those designs through planting days, etc.

Injury prevention

Injury prevention through environmental design (IPTED) is informed by universal design, which promotes the safe and dignified use of public space. Injury prevention minimises risk and provides clear and safe access for the public, including through riparian reserves and stormwater management areas. Injury prevention is also important for maintenance staff to safely undertake their operational tasks, which are sometimes performed during storm events.

Perceived risk of natural outdoor areas should be balanced with the ultimate benefits of these environments to public health through the treatment of air and water quality, moderation of dust, noise and light pollution, and the psychological benefits of natural refuges in urban settings.

Stormwater management should also consider the building consent process, with adherence to codes of practice, consideration of the stability of foundations and subsoils, and provision for access and egress as appropriate. The Health and Safety in Employment Act (HSE, 1992) is also relevant for operation and maintenance. Potential areas of IPTED responsibility for stormwater management include:

- Vehicle sight lines and general visibility of landscape and stormwater management features in streetscapes, including kerb-less carriageways, etc.
- Freedom of access for wheelchairs and prams
- Potential falling hazards and obstructions
- Change in surface levels and materials beside accessways
- Opportunities for the visually impaired to access or transect stormwater management features and natural areas, while avoiding areas that may entrap or endanger them
- Providing tactile surfaces and continuous edges to assist the visually impaired with wayfinding
- Direction on potential safety issues, especially for the awareness of parents and children
- Maintenance programme to prevent any impediments to public access
- Limbing of trees and plants that may cause harm beside accessways
- Material selection to minimise harmfulness (toxicity, sharpness, slipperiness, etc.)
- Steep slopes should be broken by slope breaks or vegetation
- Prevention from entering surface ponds and wetlands where contact recreation is not promoted, but also assisting exit form these areas (through shallow sides or benches) if entered
- Lighting of accessible reserves as appropriate.

Kanazawa Museum of Contemporary Art, Japan

B7.0 Maximise return on investment

New Zealand and international literature highlights significant cost savings and higher social, financial and environmental returns from WSD approaches to land development (Shaver, 2010b; MacMullan & Reich, 2007; Water by Design, 2010). This is an effective response to stormwater discharge consents and the Auckland Long-term Plan (LTP) processes, which consider financial and broader economic attributes to inform funding priorities. Financial incentives are also an important driver for land development professionals seeking a return on investment. The discussion below seeks to inform financial decision-making for WSD in the following ways:

1. Provide perspective on the costs and savings of WSD
2. Review the broad return on investment of WSD approaches
3. Review potential ways to analyse the economics of WSD (using a total economic values framework or extended cost-benefit analysis including consideration of provisioning, regulating and cultural benefits).

B7.1 Cost and savings of WSD

A number of studies compare construction costs of WSD against conventional approaches to stormwater management. These show that WSD capital costs are broadly equivalent to conventional approaches and can be markedly less in greenfield sites (Environmental Protection Authority Victoria, 2008; Shaver, 2010a; Lloyd et al., 2004).

Design costs

There is a perception in the development industry that WSD requires more input from designers with an associated increase in up-front design costs. There is also a perception that obtaining regulatory approval can take longer, leading to longer timeframes before development rights can be secured, potentially affecting loan repayments or timeframes for due diligence.

From a medium to long-term perspective, the up-front time required to achieve a consensus within a design team reduces design iterations going forward, avoids ‘fatal’ design flaws, and potentially saves time and money. Consent processing timeframes will become more efficient as WSD aligns more closely with the evolving policies and objectives of the PAUP.

Generally the potential up-front costs associated with WSD tend to favour land development professionals with a longer term outlook and an appropriate level of financial equity. Alternatively a developer can approach the Council early in the design process to seek opportunities for collaboration if any opportunities exist for public-private partnerships.

Construction costs

In the instance of a greenfield development, a WSD approach minimises site disturbance, reducing the extent of bulk earthworks, stockpiling and disposal. A smaller construction footprint lowers the risks associated with an 'open site' and also reduces the need for sediment and erosion control measures and associated costs.

Capital costs

The majority of potential cost savings for WSD is through reduced infrastructure demand (Wise et al., 2010). A compact development form promoted by WSD requires less infrastructure for stormwater, roading, etc. Potential savings have been shown between 10-25% for clustered versus conventional development in the US (Conservation Research Institute [CRI], 2005).

Specific WSD approaches can further reduce infrastructure requirements. While pervious pavement can be more expensive than other surfaces, depending on the product, pervious surfaces can lower total development costs by as much as 30% through reducing stormwater runoff volumes (CRI, 2005).

There is also a potential direct cost saving in using WSD approaches. Swales and raingardens are generally less expensive than piped infrastructure, especially if the number of catchpits is reduced. The cost differential may be as much as 80% for swales and 30% for raingardens (Lloyd et al., 2002). Comparison costs are available through *COSTnz*, developed by Landcare Research, which compares the acquisition, maintenance, and decommission costs of stormwater management practices based on New Zealand data (Ira et al., 2008).

Clearwater Resort, Canterbury

Operation and maintenance costs

WSD generally results in a reduced level of infrastructure in a catchment, with corresponding savings in operational budgets. It is important to note that maintenance frequency and responsibilities need to be considered. Devices on private land mitigating a single dwelling should be maintained by the property owner. Where devices on private land service multiple properties, a body corporate should be set up to carry out inspections and maintenance. If the device is located in land to be vested in Council, an operation and maintenance plan should be provided and costed to allow Council to plan for maintenance of the vested infrastructure. This arrangement must be approved in advance by Council.

WSD maintenance primarily involves the management of landscapes and key operational areas such as outlets. WSD devices such as raingardens and swales are relatively inexpensive to maintain, generally costing 3-4% of the total acquisition cost (Shaver, 2010a). Mowing costs can also be eliminated by planting native grasses in swales. Raingarden maintenance is estimated at 6-8% of the total acquisition cost, primarily to allow for replenishment of soil media every 20-25 years (Shaver, 2010a). However, contaminants in stormwater are generally captured in the upper 200 mm of the raingarden media and management of plants and mulch may be adequate to maintain these systems (Trowsdale & Simcock, 2008). Where raingardens have pre-treatment to capture gross sediment, the finer sediments that enter the raingarden can be assimilated and the system becomes self sustaining. In this instance, where WSD practices are properly designed and installed as part of a treatment train, they can perform for a much longer timeframe than conventional systems.

This is also the case for living roofs and pervious pavement. They can be installed with operability in mind, and require minimal maintenance. Living roofs in particular not only require minimal maintenance once established, they can also protect the roof membrane from the elements, extending the lifespan of the roof itself.

B7.2 Added value of WSD

WSD approaches ultimately provide a suite of benefits in addition to stormwater management. The following section looks at broader economic and community values associated with WSD approaches, from direct or indirect use.

Direct values

The land developer

A clustered development form promoted by WSD directs land development to the most appropriate location irrespective of zoning provisions. This can potentially increase a developer's yield while lowering unit costs by reducing infrastructure requirements, as previously discussed.

The marketability of a WSD development is greatly enhanced through additional natural areas and increased open space. This often represents less time in the marketplace and a premium price. Clustered housing has been selling in the US at over US$5,000 more on average than housing on conventional subdivisions (Powell et al., 2005). Communities with increased levels of open space, and properties that abut a park or wetland area, are reported as having a significant increase in property value (Natural Economy Northwest, 2008; Crompton, 2005; Emmerling-Dinovo, 1995).

Clearwater Resort, Canterbury

Landowners

WSD developments are generally associated with more open space and enhanced landscape amenity. Buildings may be clustered in areas with good relative aspect and access to infrastructure. The clustered form also provides for a dynamic community structure with positive social aspects.

Communities with increased amenity are likely to retain their market value. In Seattle the retrofit of streets as 'green streets' with WSD treatments increased property values by up to 6% (North Carolina State University, as cited in Shaver, 2010a). As an indication, a study in Portland, Oregon found that street trees added an average value of $8,870 to the sale price of residential properties, and reduced time on the market by an average of 1.7 days (Donovan & Butry, 2009).

Regional infrastructure

The protection of contact recreation in our rivers and harbours is a significant issue in Auckland. The retrofit of our communities to WSD can enhance water quality through stormwater treatment practices, and through attenuating the peak flows that can be responsible for CSOs (where they exist). WSD approaches can also reduce water supply demand (i.e. if raintanks are used), sewer/stormwater pumping and associated energy demands.

WSD promotes connected open spaces associated with natural drainage patterns. This connectivity supports The Auckland Plan's visions for a 'blue-green network' of open spaces in the city, and for making freshwater an identifying feature of Auckland (Auckland Plan Directives 7.0, 7.8, 7.10). Studies of connected park systems in Boston and Philadelphia found direct use value up to $100,000 per acre of parkland (Harnick & Welle, 2009). The location of public open space in stream corridors also improves public awareness around water conservation and natural heritage issues.

B7.3 Indirect values

The indirect value of WSD can be considered as the associated environmental goods and services (i.e. ecosystem services) it provides. This can be expressed in general terms as the cost required to provide an equivalent environmental service if one were to use conventional infrastructure.

Stormwater

Protection and enhancement of existing ecosystems is a cost-effective approach to stormwater management. Rainfall capture in a tree's canopy can equate to 100 to 600 litres a year, depending on the tree species and its maturity (McPherson et al., 2006). Based on construction costs to provide equivalent infrastructure, trees have been valued at billions of dollars for stormwater management in US cities (MacMullan & Reich, 2007).

Generally WSD delivers better stormwater runoff quality than conventional stormwater management approaches. The cumulative impact of implementing WSD throughout a city would have a significant effect on the health of freshwater and marine receiving environments. This has a potential benefit to freshwater and marine fish species and recreation. In addition this is likely to have a direct effect on the prices of properties adjacent to enhanced streams and wetlands (Dornbusch & Faleke, 1974; Bicknell & Gan, 1997).

Stormwater is also a resource in itself, with raintanks and underground detention systems collecting stormwater runoff from rooftops and impervious surfaces, which can be used on-site for non-potable water, landscape irrigation, water features and passive heating and cooling. The potential cost saving from using stormwater on-site is through reducing potable water use and purchase.

Presently Auckland water is affordable and savings are equivalent to the cost to install, maintain and renew stormwater collection systems (Vesely et al., 2005). Cost savings assume there is sufficient rainfall to accommodate water demand, as transporting water to a site during droughts may add significantly to costs. From a council perspective, on-site water storage provides a distributed network, giving a more resilient water supply for communities in the event of a systems failure.

Climate

WSD is associated with enhanced riparian buffers, re-vegetation, and vegetated WSD practices, such as raingardens and swales. Important ecosystem services provided by these natural and green infrastructure components include carbon uptake (or sequestration) and reducing localised 'heat island' effects. Studies have indicated that urban forestry and associated soils can sequester over ten metric tonnes of CO_2 per hectare per year (US Environmental Protection Agency, 2010). Trees transpire to reduce ambient air temperatures in the summer, and moderate temperatures in cold seasons by reducing winds speeds and heat transfer. The combined effect can significantly reduce energy consumption (McPherson et al., 2006; Akbari et al., 1992).

Living roofs have a particularly significant effect on ambient air temperatures within and around buildings. This is based on their insulative properties and evapotranspiration around rooftop air conditioning ducts. A living roof on an office building in Chicago resulted in a 2% reduction in total building electricity consumption (Sailor, 2008). A simulation for Toronto found that 50% coverage of buildings with living roofs would be expected to reduce the city's ambient air temperature by 2 degrees Celsius (Bass et al., 2002).

Air quality

Vegetation plays a key role in Auckland's urban environments in moderating the effects of localised air pollution by absorbing contaminants such as nitrous dioxide and sulphur dioxide, and intercepting fine particulate matter that can harm human respiratory systems. Trees, landscaped areas and living roofs take up gaseous contaminants in their leaf stomata and filter fine particulate matter. The reduction in ambient air temperatures in a city also slows reaction rates of smog, which can form volatile organic compounds at high temperatures (Currie & Bass, 2008). Wider, long-term economic benefits are achieved through the consenquent reduction of negative health effects (e.g. asthma and bronchitis).

Noise

In general, vegetation by itself is largely ineffective at moderating noise. However, recent studies have demonstrated that the use of porous concrete can reduce roadway noise pollution by as much as 10 dB (Olek et al., 2003; Gerharz, 1999). The dampening effect of pervious pavement is put down to the porosity of the material and the reduced traffic speed. Field tests of living roofs in British Columbia found a relative transmission loss of 5-13 dB in low to midrange frequencies, and 2-8 dB in the high frequency range (Connelly & Hodgson, 2008). Living walls may be expected to offer similar noise insulation properties depending on structural components and soil texture.

Optional values

Optional value relates to preserving an option to utilise a resource at a later time when the economic, social or political climate may have changed. At a minimum, the protection of ecosystems by WSD approaches allows for their restoration/enhancement to achieve direct use values in the future, in effect preventing an opportunity cost. Irreversible decisions should be avoided wherever practicable such as habitat fragmentation or filling floodplains (OECD, 2000).

One of the reasons WSD and other green infrastructure approaches are not attributed their true value is the difficulty in calculating the economic value of non-market ecosystem services (Smith & Desvousges, 1986). Willingness to pay is often used to determine non-market good and service preferences. If one assumes the willingness of the public to pay for an increase in natural ecosystem values in the future, then it is reasonable to assume one avoids an opportunity cost by retaining these systems in the present (Lewis, 2003).

Bordeaux, France

B7.4 WSD economic analysis

Life cycle costing (LCC)

The Australian/New Zealand Standard 4536 defines LCC as "the process of assessing the cost of a product over its life cycle or portion thereof". These LCC models are more robust for stormwater management if they take into account replenishment costs to renew practices, and decommissioning costs to dispose of or recycle material elements (Ira et al., 2008). LCC assists with the prioritisation of immediate and long-term investments, taking into account up-front acquisition costs, cumulative interest on payments, and linking with long-term funding cash cycles such as the LTP and Annual Plans.

There are clear advantages to WSD approaches when considered under an LCC analysis, an approach already used to evaluate a 'best practicable option' for stormwater management. A clustered WSD form of development will have reduced infrastructure overall, with associated lower capital and renewal costs over the life cycle of these systems. There is an expectation that up-front costs for WSD practices will also reduce in the near future as there is a greater uptake of WSD approaches providing for more readily available, less expensive off-the-shelf solutions, and specialised design services and construction materials.

Restored ecosystems, as part of WSD approaches, are likely to have reducing maintenance costs over time and increased performance of stormwater management as vegetation and soils mature and stream channels reach equilibrium. Natural processes in WSD devices such as raingardens and swales are likely to continue operating for the life of a development if they are provided with effective preventative maintenance.

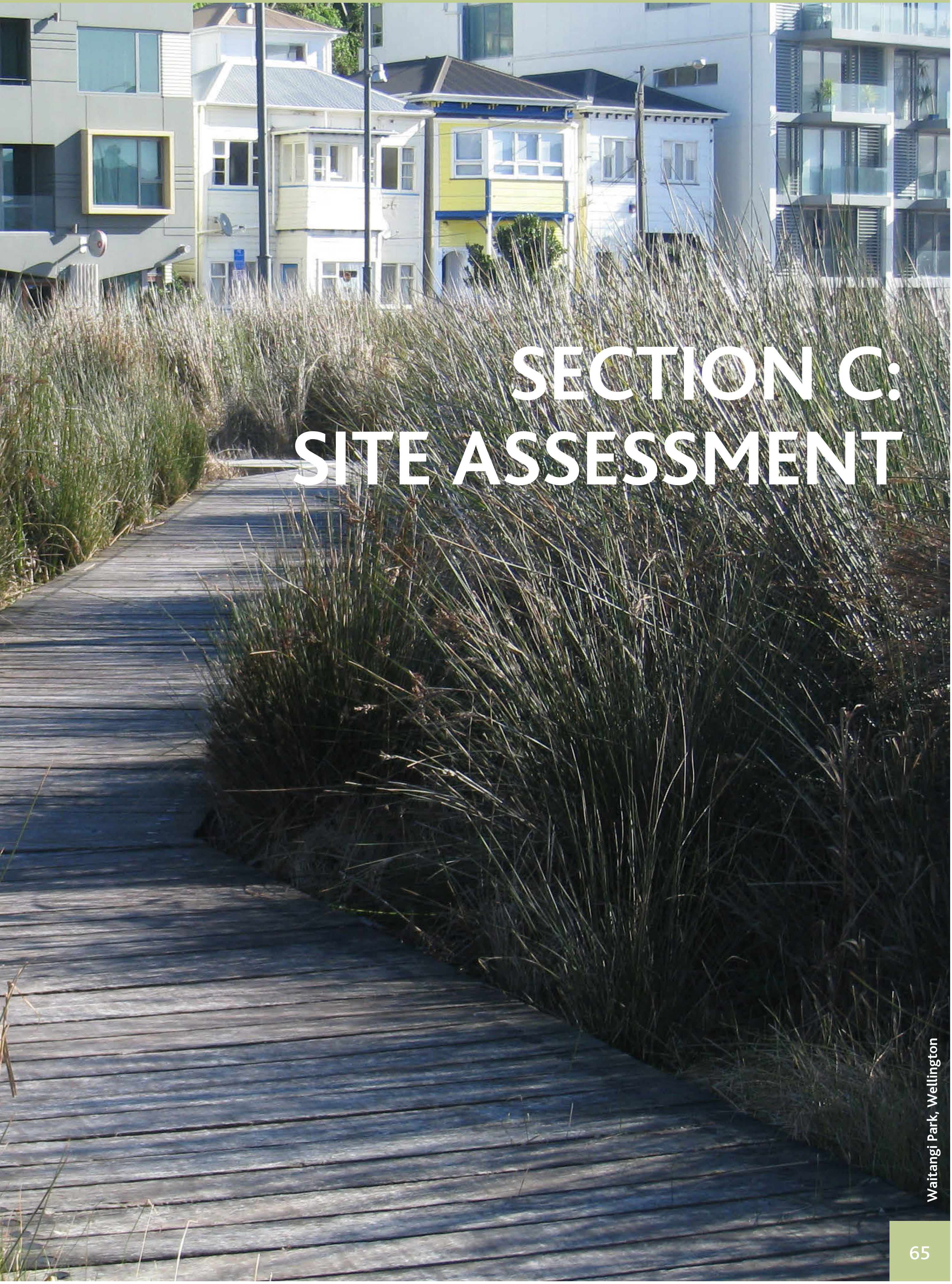
Cost-benefit analyses

A cost-benefit analysis considers the LCC against quantifiable benefits. The potential broader economic returns offered by WSD and consideration of ecosystem goods and services include:

- Water quality benefits leading to contact recreation, fisheries and tourism economies
- Optimisation of land that is marginal for development but contributes to open space networks and stormwater management
- Increased property values associated with desirable WSD developments
- Ecosystem goods and services with associated economic benefits
- Cultural and spiritual services including connection to place and indigenous biodiversity, enhancing the attractiveness of a development.

Non-financial outcomes can also be included in a cost benefit analysis, where they can be quantified and given an appropriate weighting. For example, the restoration of a lowland stream corridor could be quantified by 'habitat units', such as the length or area of restored stream corridor available to a particular species. A measurable benefit could be a standard of contact recreation that the public has previously shown a willingness to pay for, which can lead to higher property values.

Ongoing work initiated by Auckland Council will continue to contribute to the understanding of costs and benefits associated with WSD approaches in both greenfield and brownfield developments, and to add to the information already published in the Auckland Council Technical Report TR2013/043 *Auckland Unitary Plan Stormwater Management Provisions: Cost and Benefit Assessment*.



SECTION C: SITE ASSESSMENT

Waitangi Park, Wellington

C1.0 Site assessment components

A comprehensive assessment of a proposed development site is required to provide a base level of information to inform development of a WSD concept and detailed design. This information will enable design professionals to assess the proposed development against the objectives of WSD for stormwater.

Assessments also highlight the relevant regulatory issues to inform pre-application discussions with authorities. Council officers and consent regulators can play an important role in identifying potential consent impediments and clarifying any ambiguities early in the design process. The components that make up a comprehensive site assessment include:

1. An inventory of the bio-physical attributes of a site
2. Identification of socio-cultural issues and relative values of a site
3. Preliminary resource mapping to reveal land use typologies.

Site assessments should be carried out by suitably qualified and experienced professionals. Through their experience, these professionals can interpret site conditions to identify the best outcomes for land use planning, suggest the most appropriate means to avoid or mitigate potential construction effects, and identify opportunities to implement WSD.

C2.0 Bio-physical assessment

A site's physical nature can be depicted through mapping physical attributes such as geology, topography, soils, species and ecosystems, and hydrological patterns as illustrated in Figure 11. Preliminary desktop surveys and site visits may determine the need for further technical assessments, such as a contaminated soils inventory or specialist fauna surveys. Table 1 provides a list of information sources, and the potential for these to direct additional site investigations.

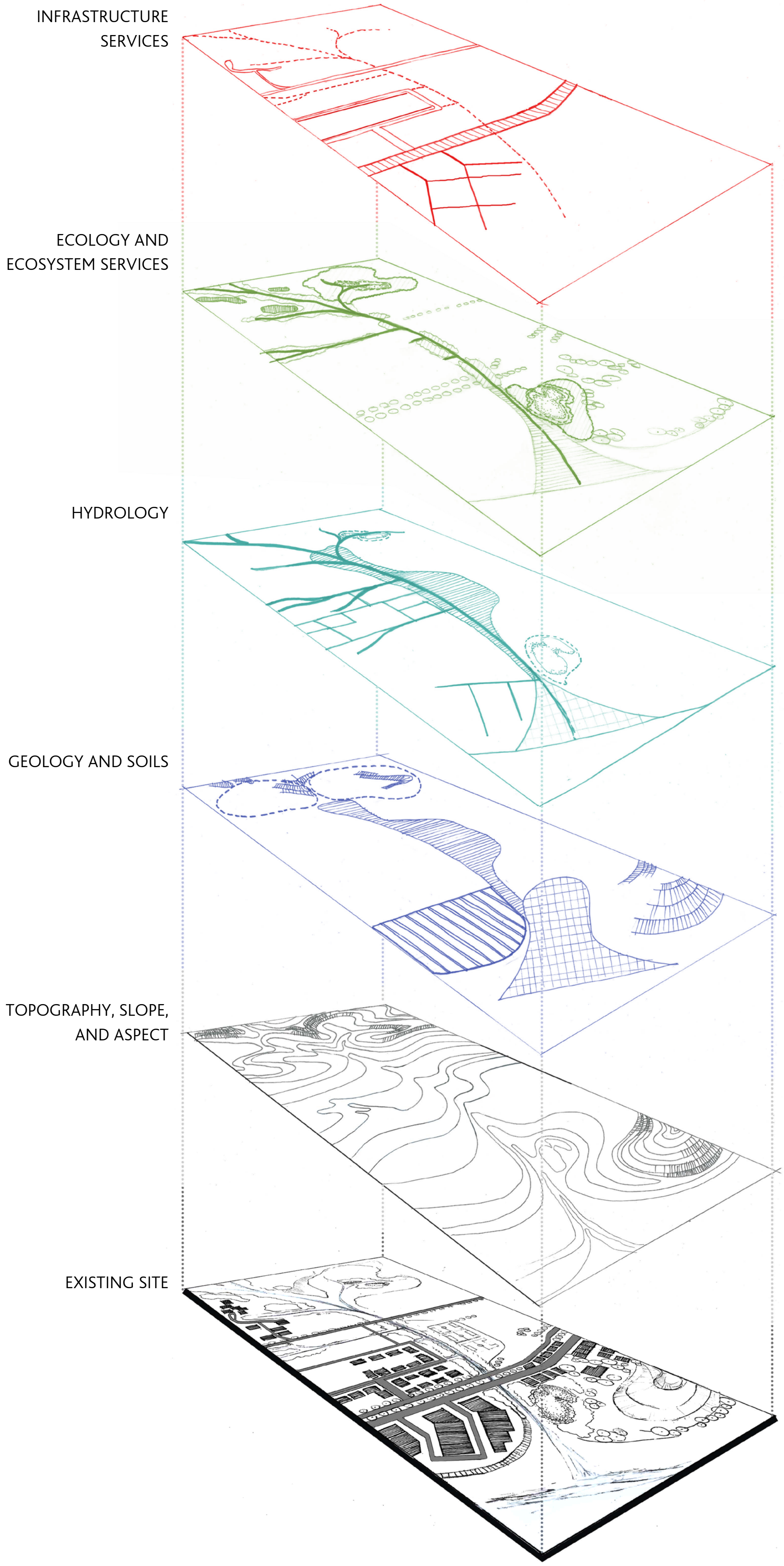


Figure 11: The layers of information that make up a site's biophysical attributes

Table 1: Bio-physical attributes

INFRASTRUCTURE SERVICES		
ATTRIBUTE	INFORMATION SOURCE	FACTORS TO CONSIDER
Drainage systems	GIS databases for wastewater, stormwater, and potable water (AC GIS viewer)	Tie-in locations and overland flow paths Possible CSO issues Existing infrastructure capacity and age Stream daylighting opportunities
Existing services	Local authority and utility service sheets for power, gas and phone (beforeUdig) Local Authority Code or Subdivision/Infrastructure Standards (AC website)	Fixed costs as immovable infrastructure Potential clashes with earthworks and services Tie-in points
Existing structures and materials	As-built surveys for landfill areas (contact AC if there is record of a landfill in the area) Extent and location of structures and impervious surfaces (AC GIS Viewer)	Contamination issues Necessity for demolition Potential for re-use of structures or surfaces
Hazards	City hazard register and LIMs (AC website) Building Code (DBH website) Local Authority Code or Subdivision/ Infrastructure Standards (AC website)	Absolute hazard constraints and appropriate buffers Existing flooding and overland flow paths Erosion issues Resilience of services
Access	Existing paper roads Predicted road classification and standards Walk, cycle and open space connections Public transport access	Integration with existing streets and entries Existing traffic contribution Priority cycle and pedestrian connections
ECOLOGY		
Terrestrial environments	Scheduled trees (AC website) Protected Natural Area surveys Land cover database (LENZ) (Koordinates.com) Reserve Management Plans (AC website) Conservation Management Strategies (DOC website) Site survey of lizards, invertebrates, avifauna, and bats (may be required; consult an ecologist)	Vulnerable or valuable habitats to avoid and/or buffer Potential to enhance existing vegetation An environmental framework to augment and connect remnant vegetation
Freshwater environments	Physical habitat surveys, including Stream Ecological Valuations (SEVs) (may be required; consult an ecologist) Macroinvertebrate and fish surveys (may be required; consult an ecologist) Freshwater fish database (NIWA website) Regional Plan: Air, Land & Water (AC website) Watercourse management plans (contact AC)	Value and sensitivity of freshwater habitats Potential for receiving environments to detain and treat stormwater if enhanced Permanent and seasonal wetlands
Coastal environment	Regional Plan: Coastal (AC website) Network discharge consents (AC GIS viewer) Coastal and inter-tidal survey (may be required; contact a marine biologist) Marine and estuarine bird surveys (may be required; contact a marine biologist or ecologist)	Value and sensitivity of coastal habitats Effects from coastal inundation and storm surges Marine and diadromous fish spawning areas

HYDROLOGY		
ATTRIBUTE	**INFORMATION SOURCE**	**FACTORS TO CONSIDER**
Groundwater	Borehole infiltration tests (may be required for detailed design; contact a geologist or geotechnical engineer) Survey spring seepage areas (may be required for detailed design; contact a surveyor) Aquifer maps (available from AC on request)	Seasonal wetlands Water table depth
Existing impervious extent	Overlay of aerial photographs with curve number values, verified on site for vegetation and soils (AC GIS viewer)	Existing hydrological issues and potential for retrofit of pervious surface or vegetation
Catchment management	Catchment Management Plans (CMP), Network Discharge Consents (NDC) and Structure Plans (AC GIS viewer) Watercourse Management Plans (WMP) (request from Auckland Council) Flood hazard mapping (AC GIS viewer) Long-term Plan (LTP) stormwater directives (AC website) Annual plan (AC website) Asset Management Plan (AC website) NIWA and archive water quality indicators (may be required; protocol is available from NIWA website)	Upper-catchment contributions Receiving environment sensitivities and values Spatial planning context Catchment-wide stormwater objectives Priority infrastructure Existing flooding issues
Hydrology	Flood modelling for 2 year, 10 year, and 100 year events (required for detailed design, contact a stormwater engineer or hydrologist) Attenuation targets (AC website)	Model existing capacity Classify streams and water bodies Stormwater discharge targets
Contaminants	Contaminant Load Model (request from AC) Point source contamination monitoring (may be required for industrial sites; contact an environmental engineer or scientist) Stream Ecological Valuations (SEVs) (required if modifying watercourses; contact an environmental engineer or scientist)	Identify existing contaminant loads and hot spots

GEOLOGY AND SOILS		
Geology	Fault lines from GNS Science (GNS active fault viewer)	Hazards
Soils	Land Environments of New Zealand (LENZ) data (Koordinates.com) Auger surveys at recommended distances (Ross, 2007) (may be required for detailed design; contact a geologist or soil scientist) Soil compaction/permeability testing (may be required for detailed design; contact a geologist or soil scientist) Landcare S-mapOnline (smap.landcareresearch.co.nz)	Geotechnical issues Soils prone to surficial erosion Soils as an agricultural resource Organic soils and peats to harvest as a soil media Soils with infiltration and recharge capacity Potential contamination

TOPOGRAPHY, SLOPE AND ASPECT		
Topography	LIDAR data (AC GIS viewer) Topographical survey (required for detailed design; contact a surveyor)	Analysis of slope and aspect Sub-catchment definition Hazards and steep slopes Inter-visibility analysis

C3.0 Socio-cultural assessment

Socio-cultural assessments are most relevant when considering 'infill' or 'adaptive re-use' development scenarios, or when adjacent to existing communities. However, in all circumstances there will be social infrastructure to integrate into designs and wider stakeholder groups to consider.

Some of the common social and cultural constraints and opportunities associated with development projects are illustrated in Figure 12 and listed in Table 2. Consultation is a key step to inform communities and develop a working relationship with them. Communities can often impart key anecdotal information about a site. Active engagement with communities can also facilitate regulatory approvals and reduce potential issues during construction phases. As a minimum, early engagement should be undertaken with neighbours, iwi and community groups, ideally using public engagement specialists, and potentially following the preparation of a consultation plan.

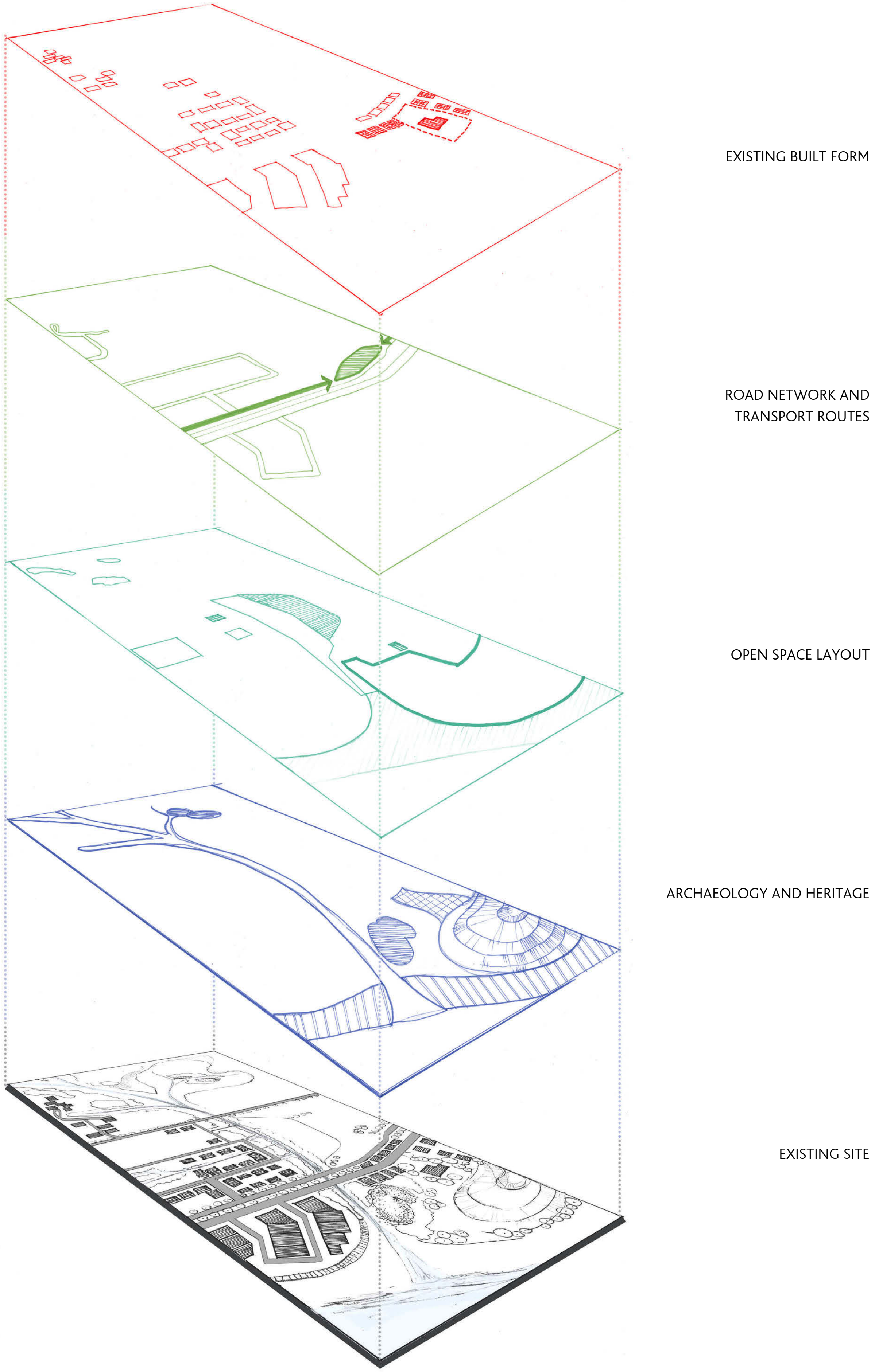


Figure 12: The layers of information that make up a site's socio-cultural attributes

Table 2: Socio-cultural attributes

ATTRIBUTE	INFORMATION SOURCE	CONSTRAINTS AND OPPORTUNITIES
EXISTING BUILT FORM		
Cadastral	PAUP (AC website) Reference structure plans (AC GIS viewer) Pre-application meetings with planning officers (contact Auckland Council)	Potential for flexible provisions around development controls, including yards, height to boundary, lot sizes, access and noise
Existing density	PAUP (AC website) Discussions with planning officers for regional strategy and urban design (contact Auckland Council)	Overall density provisions – noting that in a brownfield area subject to intensification this may be a minimum number of lots/units rather than a maximum number
Land tenure	PAUP (AC website) Survey software (Online survey software)	Affected parties and potential community and open space linkages
ROAD NETWORK AND TRANSPORT ROUTES		
Transport	PAUP (AC website) Regional Land Transport Programme (AT website) Passenger Transport Network Plan (AT website) Major Transport Project Programme (NZTA website) LTP transport directives (AC website)	Potential flexibility for street hierarchy and road design Public transport provisions Intensification around transport hubs and interchanges Walking/cycling linkages
OPEN SPACE LAYOUT		
Useable open space	PAUP (AC website) Parks and Open Space Strategic Action Plan (AC website) Reserve Management Plans (AC Website) GIS database (AC GIS viewer)	Open space planning Connection with existing open space Priority recreation facilities
Community facilities	PAUP (AC website) Council website (AC website) GIS database (AC GIS viewer)	Connectivity to community facilities Identifying and engaging with representative stakeholders
ARCHAEOLOGY AND HERITAGE		
Heritage sites and cultural landscapes	PAUP (AC website) GIS databases (AC GIS viewer) New Zealand Historic Places Trust (pre-1900) (Heritage website) Local authority iwi liaison and engagement with tangata whenua (AC website) Site survey (may be required for concept design; contact an archaeologist)	Protected heritage buildings and site features Potential acknowledgement of heritage elements and cultural values where appropriate Potential landscape connections between heritage elements

LANDSCAPE VALUES		
ATTRIBUTE	INFORMATION SOURCE	CONSTRAINTS AND OPPORTUNITIES
Landscape and natural character values	Regional Policy Statements (AC website) Regional Landscape Assessments (AC website) Parks and Open Space Strategic Action Plan (AC website)	Natural character values and sensitivities Potential landscape and visual effects
Neighbourhood character values	Community perception studies (AC website) LTP Neighbourhood Plans (contact Auckland Council) Auckland Plan (AC website) PAUP (AC website) Local Board Plan (AC website)	Neighbourhood context for density and building form Correlation with existing community planning objectives Recognised community vernacular landscape Preferred community outcomes Providing for adequate amenity and privacy in areas of residential intensification
COMMUNITY PLANNING		
Land values	Current rateable values (AC GIS viewer)	Determine target market and minimum yields for break-even
Demographics	Statistics New Zealand (Statistics NZ) Community planning (AC website) State of Auckland documents for Demographics and Quality of Life (AC website)	Determines community composition including job sector, levels of employment, and age cohort to guide the development product based on community and market demand
Future potential projects	LTP Neighbourhood Plan (AC website) Annual Plans (AC website) PAUP (AC website) Structure Plans (AC GIS viewer) Discussions with planning officers (contact Auckland Council) Sustainable Catchment Programme (SCP) Plans (AC website)	Potential reverse sensitivity issues from future proposed land use Priority future infrastructure Integration with proposed future planning frameworks Integration with proposed investment in community catchment programmes
Education facilities	Ministry of Education, Education Review Office (ERO website) PAUP (AC website)	Community planning for connectivity to schools while protecting privacy/parking concerns Opportunities for interpretation of WSD near schools
Transportation	District and regional transport planning documents (AT website) PAUP (AC website)	Consideration of future transport network Expected traffic volumes, roading hierarchies, interchanges, and mass transit Parking provision Carriageway and right-of-way provisions

B4.0 Resource mapping

The attributes identified in the site assessment should be integrated into one or more analysis drawings, referred to as resource mapping (refer to Figure 13). This analysis begins to draw out the logical land use patterns for a site, while taking into account its context and connectivity within the broader urban and ecological landscape.

Resource mapping is the basis for early design work, but it does not dictate a final development form, since a range of measures may be possible, especially in regard to regional and catchment planning considerations and early discussions with regulatory authorities.

Council information layers can be downloaded through the Auckland Council GIS viewer to add base information to resource maps. Free GIS software such as Q-GIS is available to plot council information as well as other information sources.

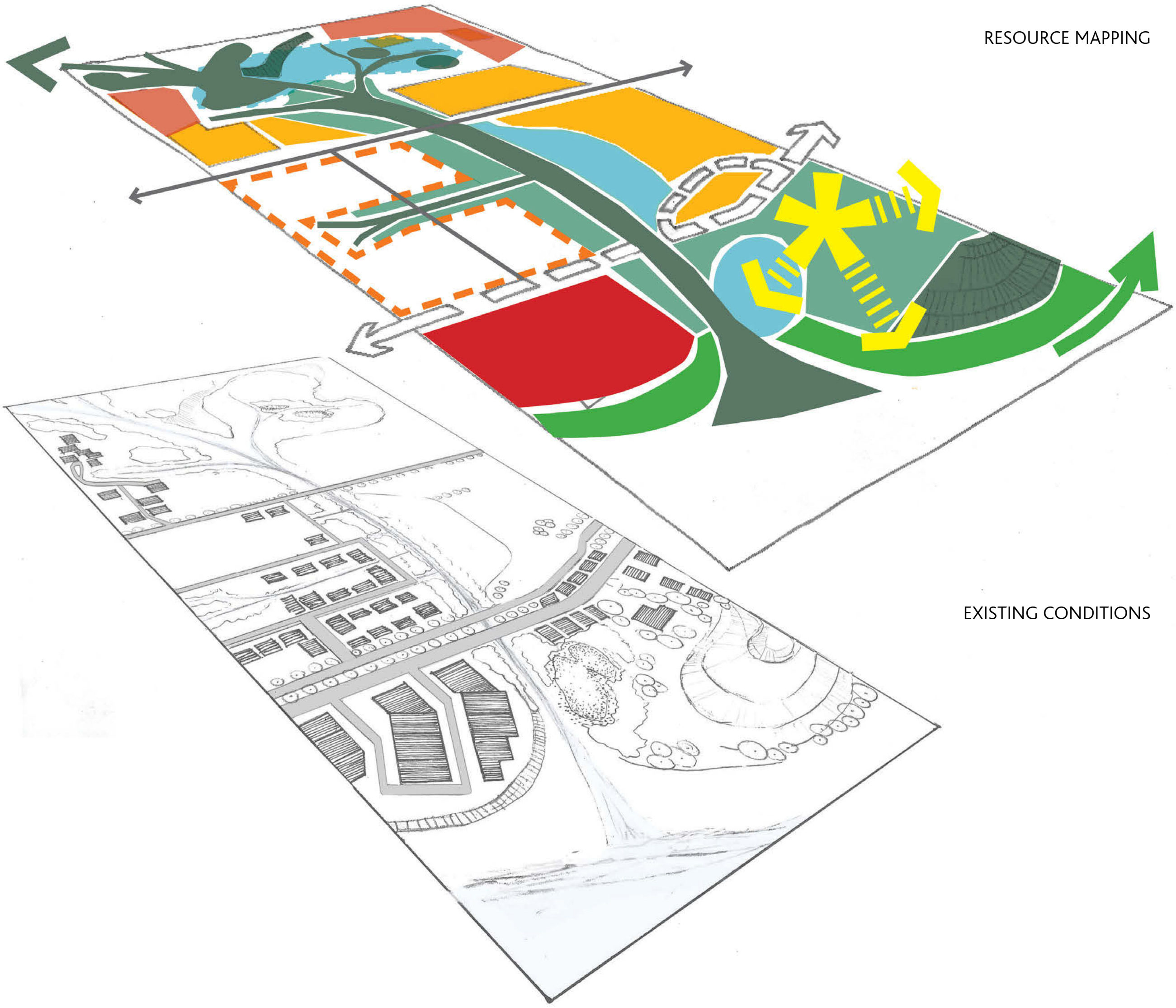


Figure 13: Resource mapping is the basis of a logical land use pattern for a site, including connections to the broader landscape.

Clearwater Golf Resort, Christchurch

SECTION D: SITE ANALYSIS

Thornton Creek Daylighting, Rainier, Washington, USA

D1.0 Site analysis process

In the Site Analysis phase of design, the project team uses the resource mapping (from the Site Assessment phase) to explore a potential development layout for the site. This includes the following steps, each of which should respond to the principles of WSD:

1. Develop **project objectives** based on assessment work, and WSD principles and objectives based on regional, catchment and site priorities
2. Establish an **environmental framework** appropriate to the site's ecosystem functions and values. This should support potential development with an appropriate level of environmental services and landscape values whilst meeting the objectives of WSD.
3. Prepare a **development framework** that responds to site conditions with appropriate development densities, building coverage and infrastructure services
4. Review the **site context** at the regional and catchment scales, and in accordance with proposed site-specific land uses.

D2.0 Project objectives

Prior to undertaking the site analysis, it is recommended that the project team meets to develop project objectives. This will set aspirations as well as the minimum requirements for a project in addition to statutory requirements. This should be informed by the WSD objectives introduced in Section B, including:

- Reduce stormwater runoff - reduce stormwater runoff volume and peak flow to predevelopment levels
- Manage stormwater quality - manage stormwater quality to avoid adverse environmental effects
- Minimise soil disturbance - minimise sediment in stormwater runoff, especially during construction, and protect site soil resources from modification
- Promote ecosystem health - Promote the health of regional ecosystems and their associated environmental services through the management of stormwater at the catchment and site scale
- Deliver best practice - deliver best practice urban design and broader community outcomes as part of stormwater management delivery
- Maximise return on investment - achieve maximum value from stormwater management through the consideration of a broad range of benefits.

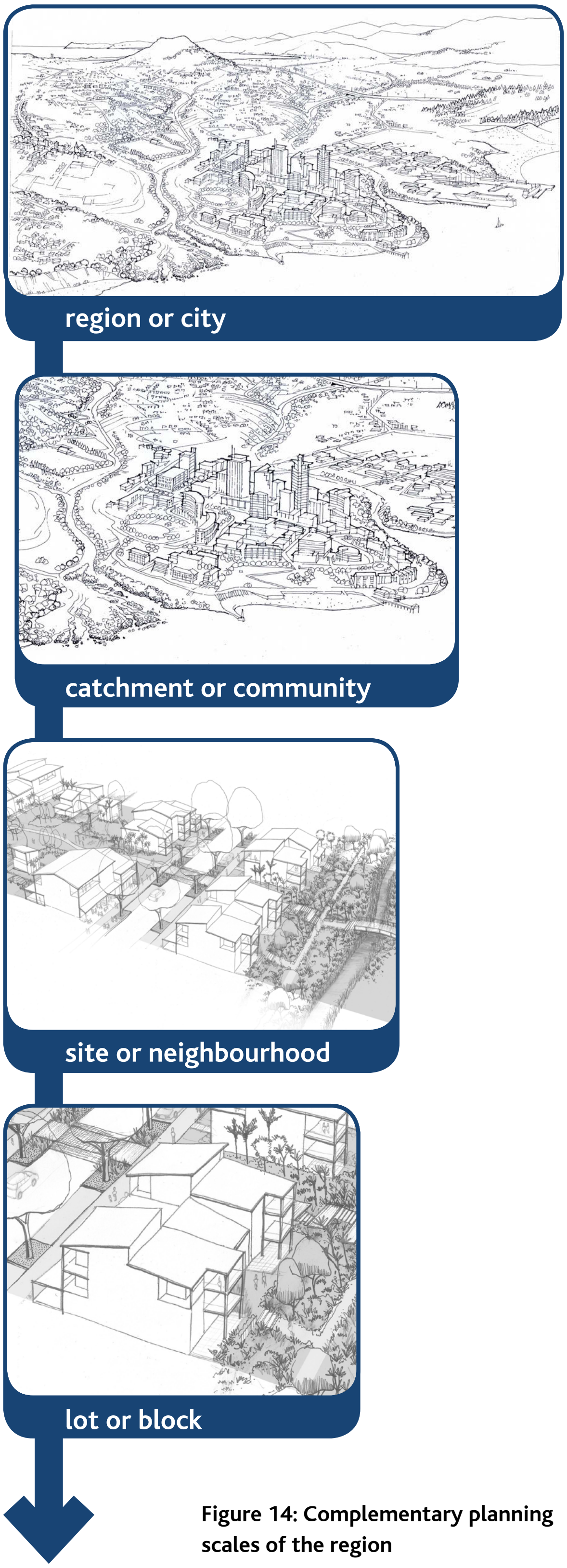


Figure 14: Complementary planning scales of the region

D2.1 The scales of WSD

In order to balance development with supporting ecosystem services, it is necessary to promote WSD outcomes at the complementary planning scales of the 'region' (in this case the Auckland region), the 'catchment' (or community), and the 'site' (or neighbourhood) scale (Figure 14).

The application of WSD principles at these planning scales is introduced below, and discussed in more detail throughout Section D.

Regional scale

The *Royal Commission Findings on Auckland Governance* (Salmon et al., 2009) called for robust, considered and consistent planning to support the region's ongoing growth and development. At the regional scale, WSD contributes to this process by promoting resilient ecosystem services to support an appropriate growth pattern.

The promotion of WSD principles at the regional scale is based on a clear understanding of the values and connectivity of ecosystem services in the region. It is also a means to promote the collaboration of stakeholders with regulators in planning processes. The WSD principles previously introduced in Section A of this guideline are presented below in consideration of the regional scale.

1. **Promote inter-disciplinary planning and design**
   Collaboration between Council units and developers can lead to opportunities for integrated objectives and priorities for infrastructure (environmental, social, property and transport).
2. **Protect and enhance the values and functions of natural ecosystems**
   Provide for the protection of representative and rare natural systems in regenerative patterns in order to achieve ecological connectivity and resilient ecosystem services in the region. Water quality requirements are often driven by the goal of protecting regionally significant ecosystems.
3. **Address stormwater effects as close to source as possible**
   Cumulative effects become significant at the regional scale. Mitigating the effects of development on the environment is difficult and costly with an "ambulance at the bottom of the cliff" approach. Mitigating issues as close to source as possible avoids these cumulative effects and provides resilient mitigation systems through the removal of central points of failure.
4. **Mimic natural systems and processes for stormwater management**
   Increase the resilience of natural systems and processes for stormwater management across the region by promoting appropriate development patterns for headwaters and aquifers, watercourses, inland lakes, isolated wetlands, and coastal areas. Look to broad regional ecosystem enhancement opportunities such as urban forestry, a system of natural floodplains, or creating large scale wetlands.

Catchment scale

The catchment is the most useful spatial planning scale for the implementation of WSD principles. There is a direct causal link between stormwater runoff within a catchment boundary, and potential downstream effects to receiving environments. Catchments are defined by topographic boundaries, which also form discrete land management units and inform the potential layout and intensity of the built environment. Catchment planning requires an understanding of three interrelated processes in the catchment:

- Land use practices generating stormwater runoff and contaminants
- The means in the catchment (natural or structural) to detain, retain, treat, convey and attenuate stormwater runoff
- The values, natural functions and intended uses of receiving environments.

The best means to apply WSD principles at the catchment scale is through the integration of parallel planning processes such as catchment management plans (CMPs), watercourse management plans (WMPs), sustainable catchment programme (SCP) plans and comprehensive development plans (CDPs). These plans can focus on converging infrastructure issues in the catchment to ensure a balance of built and natural environments, and to reflect the values and sensitivities of the receiving environment. The WSD principles previously introduced in Section A of this guideline are presented below in consideration of the catchment scale.

1. **Promote inter-disciplinary planning and design**
   WSD promotes early consultation between individuals in the Council and the development community. A working group within the Council, potentially including large landowners, can share information and mutually agree objectives and priorities for a catchment. This is a means to ensure infrastructure planning achieves multiple objectives across stormwater management, ecology, urban design and cultural values. This also provides an opportunity to combine engagement with community, iwi and public agencies on a range of issues.
2. **Protect and enhance the values and functions of natural ecosystems**
   Natural ecosystems, including vulnerable soils, groundwater aquifers, areas of terrestrial vegetation, wetlands and surface watercourses can be assessed at the catchment scale to ensure they operate as connected and therefore resilient natural systems. This includes retaining and enhancing ecological connections with adjacent catchments for broader regional landscape linkages. Natural systems can be further enhanced in areas of the catchment if they are to specifically moderate the impacts of built environments.
3. **Address stormwater effects as close to source as possible**
   WSD promotes the location of land uses based on the capability of directly affected environments. Where increased stormwater runoff is likely, a treatment train can be applied as a combination of landscape areas, swales, raingardens, restored streams, etc. acting in a sequence from the source to the receiving environment.
4. **Mimic natural systems and processes for stormwater management**
   At the catchment scale, natural systems and processes can be complemented with interventions such as raingardens, remediated soils and revegetation in upper catchment areas; restored streams, wetlands and swales attenuating flows in mid catchment areas; and broad natural floodplains and enhanced receiving environments in the lower catchment.

Site scale

The site scale is usually the most relevant to land developers. It is informed by regional and catchment planning as discussed above, but there is also a more detailed assessment which informs planning and design outcomes. The site planning process is covered in detail in Section D5.3, and is summarised below in terms of the WSD principles previously introduced in Section A of this guideline.

1. **Promote inter-disciplinary planning and design**
   An inter-disciplinary team provides a comprehensive assessment of a site's attributes, identifies project risks, and promotes multiple project objectives. An inter-disciplinary approach also captures engagement with relevant community stakeholders.
2. **Protect and enhance the values and functions of natural ecosystems**
   WSD promotes a development layout, architecture, and construction methodology that avoids valuable or sensitive ecosystems and/or buffers these systems from potential impacts of stormwater runoff. A site's ecosystems can also be enhanced from a predevelopment condition to moderate any impacts from development.
3. **Address stormwater effects as close to source as possible**
   A site's layout can minimise impervious surfaces and thereby reduce stormwater runoff generation at source. Where runoff does occur, it can be captured and treated from the source to when it leaves the site, in multiple and complementary treatment approaches (a treatment train).
4. **Mimic natural systems and processes for stormwater management**
   'Natural systems and processes' for stormwater management include infiltration, evapotranspiration and open stream systems. Treatment practices that mimic natural sytems and processes include living roofs, raingardens, swales and wetlands. All of these natural systems help to prevent stormwater runoff generation, and capture and treat runoff when it does occur. They also provide a suite of other ecosystem services and amenity benefits for a site, such as the moderation of heat, dust and light.

D3.0 Environmental framework

Two of the four principles of WSD refer to natural systems, namely **'Protect and enhance the values and functions of natural ecosystems';** and **'Mimic natural systems and processes for stormwater management'.**

An environmental framework such as that in Figure 15 determines the value of existing on-site environmental resources at the regional, catchment and site scale. Site layout is then optimised to protect and enhance on-site resources. An environmental framework is built from the data collected during the Site Assessment phase.

An environmental framework is a means to ensure that sufficient ecosystem services are provided in a site or catchment to support the wellbeing of communities in current or future developments. It ensures the principles of WSD are considered by protecting and enhancing a site's natural systems across open space networks, ecological corridors, receiving environments and enhanced landscapes. A project team will generally consider the following site elements or attributes as part of a combined environmental framework:

- Landscape and natural character values
- Soil and riparian ecosystems
- Biodiversity values to ensure native species resilience
- Ecosystem connectivity to ensure ecosystem resilience.

To assist with the determination of values, Auckland Council has produced several documents which provide guidance for developing an environmental framework. These are:

- TR2009/083 *Landscape and Ecology Values within Stormwater Management* (Lewis et al., 2010)
- *Criteria for the Identification of Significant Ecological Areas in Auckland* (Sawyer & Stanley, 2012).

Environmental frameworks are prepared by ecological and landscape specialists to ensure the classification and optimisation of on-site resources is completed correctly. Getting these specialists involved early on in the Site Analysis phase provides the best opportunity to maintain and enhance the environmental resources of a site.

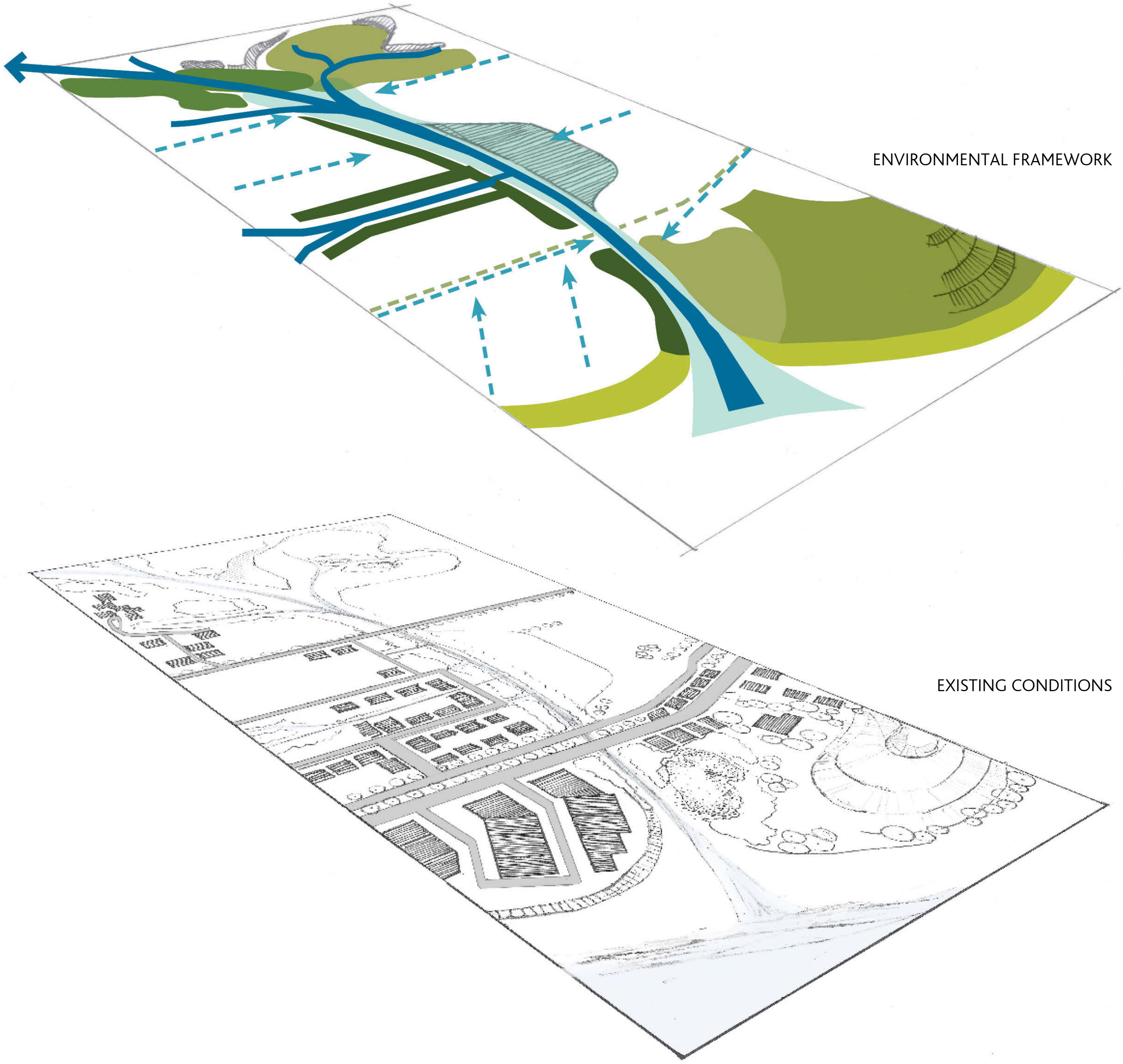


Figure 15: An environmental framework ensures enhanced ecosystem services to support potential development.

Kotuku Park, Kapiti

D3.1 Landscape and natural character values

An environmental framework preserves the unique landscape attributes of a site by protecting, restoring and buffering significant elements. Landscape attributes are captured as part of the Site Assessment phase summarised in Tables 1 and 2. The attributes that make up our landscapes include:

1. Biophysical elements, patterns and processes
2. Sensory qualities
3. Spiritual, cultural and social associative activities and meanings.

The aim is to maintain and enhance these values within the development form. There are strong networking effects when these attributes are combined into a recognisable landscape pattern i.e. the attributes combined are worth more than the sum of their parts.

For example, when an isolated gully system is connected to an intact stream corridor, it enhances the natural drainage pattern of the site, the associated natural character values, the ecological connections in the catchment, and the landscape coherency. It may also assist in the visual mitigation of buildings and infrastructure. For further information, refer to Section B.

Further discussion on landscape and natural character values can be found in Auckland Regional Council Technical Report TR2009/083 *Landscape and Ecology Values within Stormwater Management* (Lewis et al., 2010).

D3.2 Soil resources

A pre-disturbance soil survey by a geologist or soil scientist is recommended during the Site Assessment phase to map beneficial soil resources, soil liabilities, and relative geotechnical constraints. These surveys can direct the location of buildings, infrastructure and environmental systems. For example, stormwater management areas and deep-rooted trees are best located on granular or allophanic soils.

Pre-disturbance surveys may also reveal suitable resources for bioretention practices (sandy loams) or wetlands (organic soils and peats). However, it is important to remember that Auckland soils vary over tens of metres, and unintentional mixing can potentially lend poor properties to ‘good’ soils.

Further sub-soil surveys may be undertaken if the infiltration rate identified in the pre-disturbance survey is low, or if planting is to take place on the cut faces of earthworked areas.

Discussion on soils can be found in Section B and TR2009/083 Auckland Regional Council Technical Report TR2009/083 *Landscape and Ecology Values within Stormwater Management* (Lewis et al., 2010).

D3.3 Riparian ecosystems

A fundamental objective of WSD is the protection of streams, wetlands and estuarine environments from the impacts of their contributing catchments. It also seeks to protect headwater environments, which represent 90% of Auckland streams (O'Brien 1999). Headwater environments are ephemeral and intermittent watercourses upstream of permanent watercourses. A watercourse classification may be carried out (consult an ecologist) as part of the Site Assessment phase to determine the classification of watercourses in the development.

WSD promotes the enhancement of these headwater systems for their inherent values (landscape and ecology), their environmental services (including stormwater management), and to ensure the resilience of these systems to catchment change.

An environmental framework must take into account the relative values and functions of riparian systems from a catchment and regional perspective, as well as the vulnerability of these systems to catchment stressors. The framework looks at the long-term sustainability of these riparian systems, including providing for appropriate riparian buffers, flood mitigation and ecological value.

If streams are already affected by existing adverse catchment conditions, the project team may consider rehabilitation of a stream or increasing the stormwater management functions of these systems through some of the responses discussed below.

Promotion of continuous stream corridors

Greenways, also known as lineal parks, wildlife corridors or riverways, were previously discussed in Section B. They are lineal open spaces linking natural, cultural and recreational areas in coincidence with streams or other lineal landscape features. Greenways provide the framework to protect, conserve and link natural resources and open spaces, including fragmented urban habitats. An example of a greenway in the Auckland region is the Twin Streams project that aligned asset managers and community groups behind a collective vision for two significant Waitakere watercourses and their associated open space. Currently, greenways are being promoted by Auckland Transport and Local Boards for walkways and cycleways while including the "green" elements of streams, green infrastructure and ecological corridors where possible.

Stream corridors in Auckland are often marginal areas for built development due to flooding constraints and climatic conditions, but they can have significant value as open space linkages between coastal open space, ridgelines and volcanic cones.

Protecting and enhancing natural stream morphologies

Streams are dynamic systems that change frequently along their length through natural pool-riffle-run sequences (refer to Figure 16), and across their width from stream margin, to banks, floodplains and tributaries. To ensure a sustainable stream system, a project design team must consider the underlying geology, hydrology and ecology to provide for a stream in equilibrium with its floodplain and catchment.

WSD promotes the use of bioengineering approaches to stream restoration, which utilise natural materials working in combination with appropriate stream morphologies to detain and convey stream flows. Additionally, aquatic diversity can be deliberately included in stream restoration projects through purpose-built habitat or enhanced fish passage.

Promotion of riparian buffers

A riparian zone is the area of land adjacent to streams and rivers that is the transition between land and water (Becker et al., 2001). This includes land from the water's edge, stream banks and adjacent floodplains that are periodically inundated. Riparian buffers and natural floodplains can be accommodated within development as part of a broader open space network, or enhanced for an inherent stormwater management function.

It is appropriate to apply a flexible approach to riparian buffers accounting for the following attributes:

- Geotechnical stability of adjacent land
- Spring seepages, isolated wetlands and extent of flooding
- The values of existing riparian vegetation
- A sustainable buffer width to achieve minimal ongoing maintenance of weeds
- A predicted stream profile based on an urbanised catchment
- The predicted meander alignment of a stream
- Safe public access, including visibility
- Parallel stormwater management treatment opportunities
- Pedestrian and road crossing points
- Priority ecological connections for distribution of flora and fauna between catchments
- Stream habitat diversity.

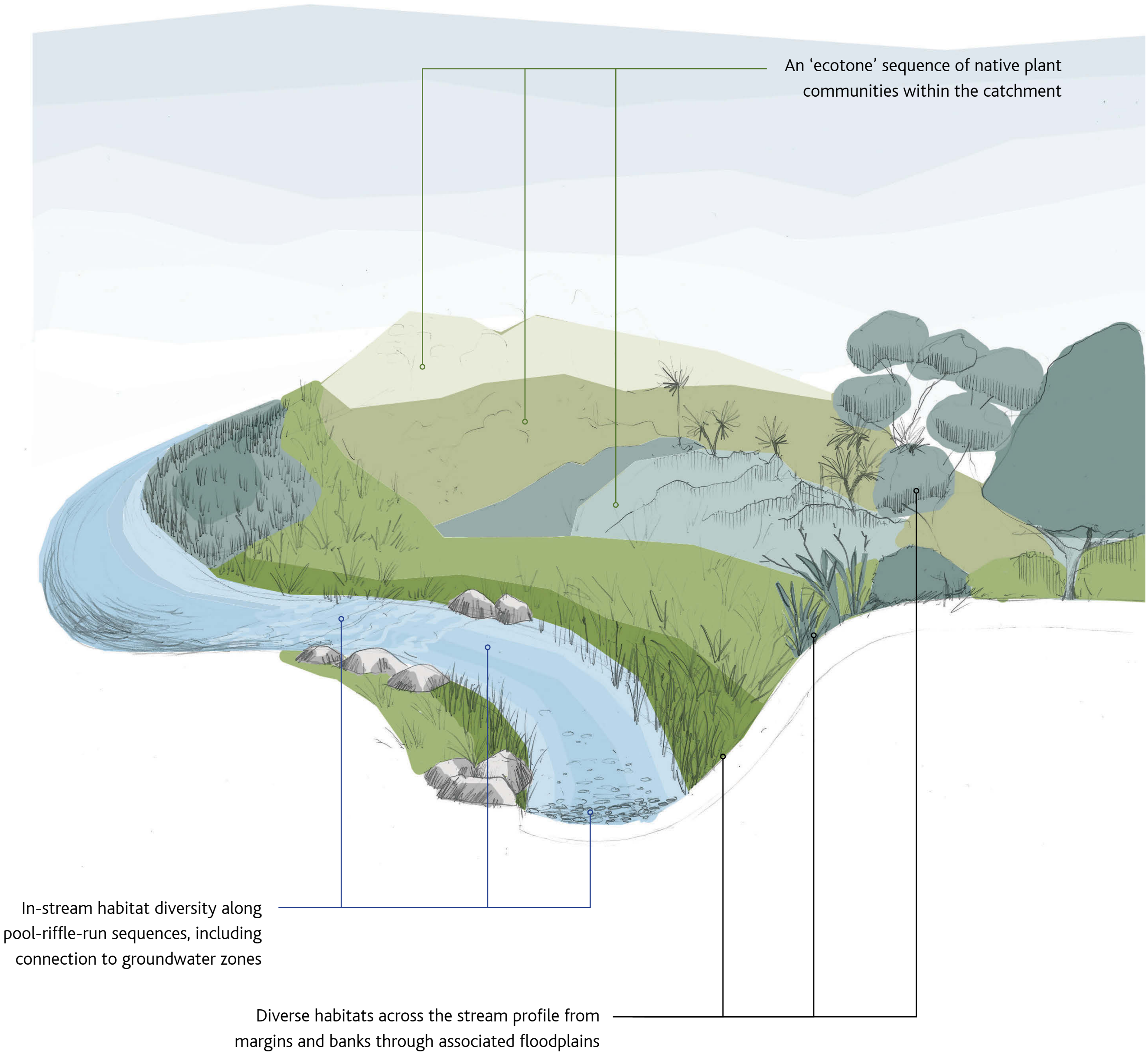


Figure 16: Diversity of stream habitats across latitudinal and longitudinal gradients of a stream environment

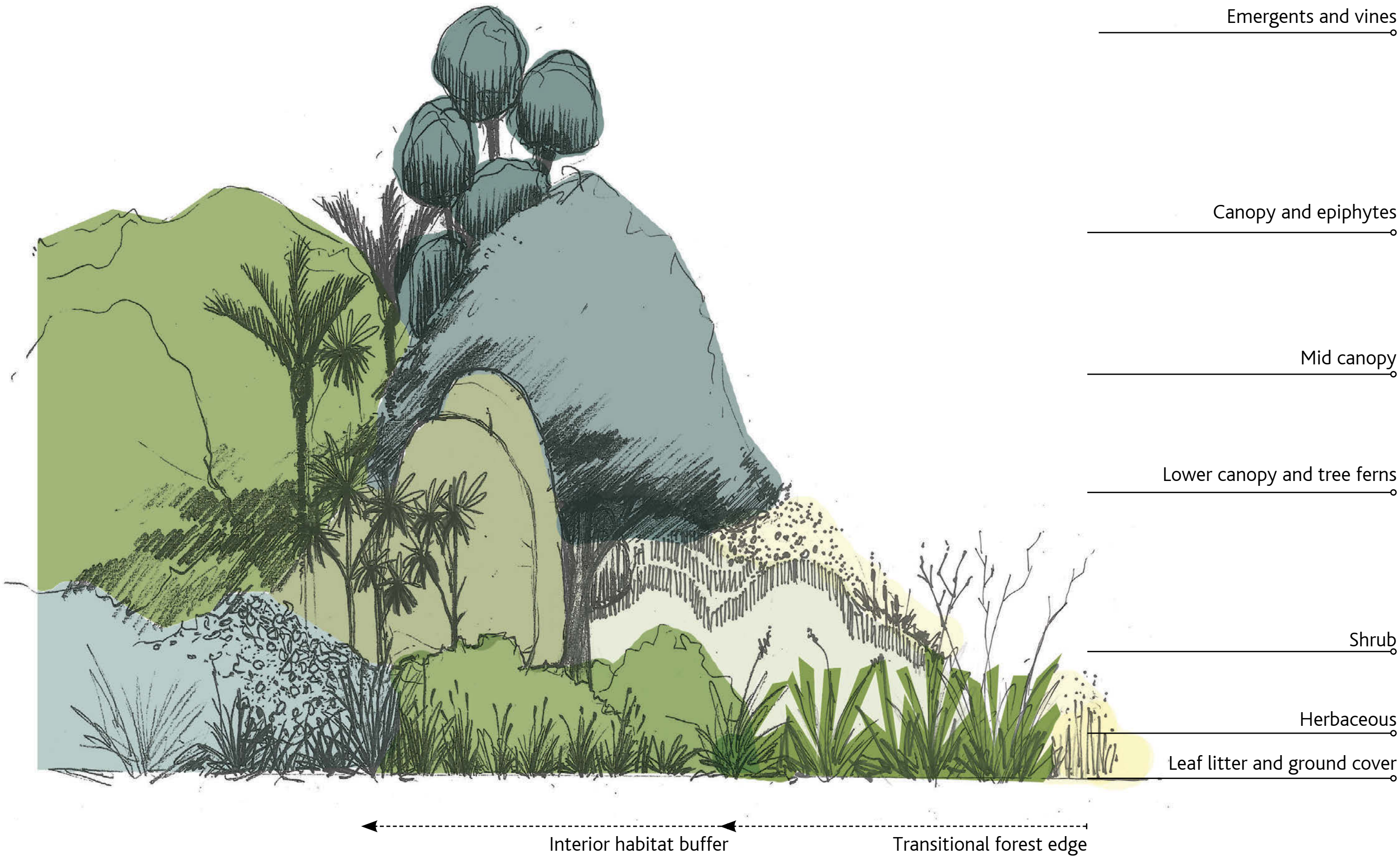


Figure 17: Diversity of habitats within the tiers and edges of a forest

D3.4 Ecosystem diversity

Ecosystem diversity is to be assessed using the *Criteria for the Identification of Significant Ecological Areas in Auckland* (Sawyer & Stanley, 2012) published by Auckland Council. Relevant assessment criteria include:

- Representativeness - a factor that assesses the types of ecosystems and the species that live in them against Auckland's original ecosystem types
- Threat status and rarity - an assessment of the threat of extinction or decline of all levels of biodiversity (genetics, species, communities, habitats and ecosystems) at all scales (site, catchment, region and nationwide)
- Diversity - an assessment of the different drivers at different scales including aspects such as competition between species, disturbance history, climatic variables and landform
- Uniqueness or distinctiveness - an assessment of whether the environmental resource only occurs in the Auckland region.

Terrestrial habitat diversity

Diversity assessment will consider the regional and catchment significance of site resources. WSD promotes the protection and enhancement of diverse native vegetation types. This may include the following potential land management responses:

- Provide a planted riparian buffer to protect existing 'interior' habitat from disturbance and thereby protect unique microclimates and associated habitat diversity
- Re-vegetate a site with pioneer vegetation species to develop soils and allow for natural succession processes to occur
- Enhance a site by planting complementary flowering and fruiting species to extend food sources for native fauna
- Restore multiple vertical vegetation 'tiers' from root zones and litter layers, through herbaceous plants, shrubs, canopy, and emergent trees to form diverse habitat niches (refer to Figure 17).

Plant species diversity

In addition to their natural character and ecosystem values, native plant species have good survivorship and often require less replacement and maintenance than introduced species over the long-term. 'Eco-sourcing' involves the collection of divided plant material or seed from remnant vegetation as close as possible to the location of proposed planting, and ideally from a similar ecotone (a similar environment in terms of climate and elevation). This is a means to protect unique genotypes of plant species, which can also be best suited for the local environment.

D3.5 Ecosystem connectivity

Ecosystem connectivity enables the drift of individuals within a species through an environment in order to provide for different aspects of their life cycle or to populate (reproduce) in other areas. This assists the long-term resilience of representative native communities.

Linkages can be established by movement corridors and/or 'stepping stones' of supporting habitat across the landscape. Distribution requirements are extremely variable for individual species. Some species, like bellbirds, are unable to traverse even leafy suburbs, while skinks, if they can avoid predation, require only a stone wall or single line of plants to move through the landscape. *The Criteria for the Identification of Significant Ecological Areas in Auckland* (Sawyer & Stanley, 2012), published by Auckland Council, contains guidance on connectivity assessments under the criteria of stepping stones, migration pathways and buffers. Various studies have been undertaken, especially for dispersal of bush birds, providing for the general distances traversable by wildlife (Meurk & Hall, 2006) as shown in Figure 18.

Potential ways that an environmental framework might enable ecosystem connectivity include:

- Protect headwaters, springs and isolated wetlands as a source of invertebrate life and nutrient energy
- Promote revegetation of steep slopes and visible ridgelines for upper catchments, while allowing for potential cross-catchment connections
- Ensure there is sufficient area for self-sustaining wetland and floodplain environments and their associated riparian buffers
- Promote diverse native planting for landscape areas
- Form continuous landscape elements such as intact stream corridors
- Protect, enhance or create an urban forest through the collective planting of parklands and streetscapes
- Protect diverse habitats at the interface of coastal, freshwater and terrestrial environments
- Increase diversity within stormwater infrastructure projects such as wetlands for state highways
- Protect and enhance fish passage, including access to additional habitat such as stormwater wetlands
- Provide flowering plants for pollinators, and a variety of nectar and fruit sources for avifauna and lizards.

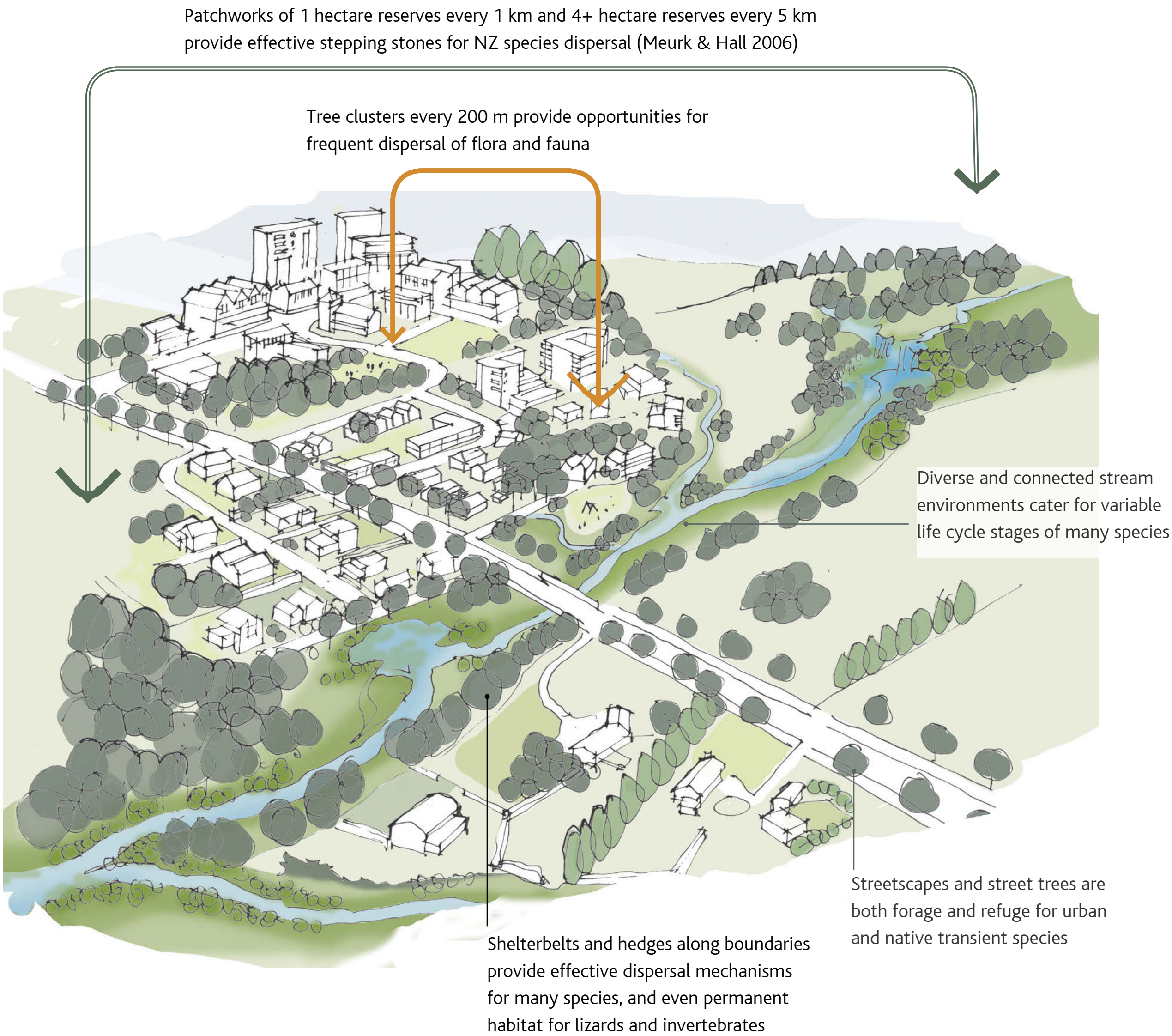


Figure 18: The potential for ecological connections across human environments (adapted from Meurk & Hall, 2006)

D4.0 Development framework

Resource mapping identifies areas of the site which are optimal for development, or are limited by constraints. For example, flat areas of land with good aspect and existing access may be ideal to 'cluster' development, whereas gullies or steep slopes may require a more creative design approach in terms of access and architecture. Other development frameworks include infill and brownfield development and mixed use developments. An example of a development framework is shown in Figure 19.

WSD is not a universal solution for land development and there may be instances where a site is too sensitive, or its values are too significant, to suggest development in any way. WSD encourages increased density and mixed use responses within the best development areas, including the retrofit of existing built environments. This preserves a substantial balance area of open space for its values and associated ecosystem services.

D4.1 Clustered development

Lot layout is often the most enduring legacy of development. It is therefore central to a WSD approach that planning provisions allow for a flexible and responsive development form. 'Clustered development' is a potential mechanism to increase density or built form in appropriate areas of a site or catchment in order to preserve the balance of area for ecosystem services. Additional benefits of clustering include:

- Reducing impervious surfaces, thereby reducing requirements for stormwater management
- Reducing capital costs through reduced infrastructure per lot/unit
- Living roof and pervious paving technologies become more affordable with increased densities, and these approaches subsequently mitigate the need for larger stormwater management responses such as detention ponds.
- Directing development to the most amenable sites in terms of aspect and constraints
- An increased level of open space, providing associated market premiums
- The potential for incorporated groups to manage private commons and enhanced amenities
- A heightened sense of community and security, and a critical mass for public transportation.

Often clustering requires an increased level of landscape amenity to balance and mitigate dense built form. This includes enhanced streetscapes and open space amenity, which also ultimately provides the developer with an added value product. Effective design can provide for both increased density and privacy through the careful handling of private to public transitions.

Clustered development is more frequently the result of a structure plan or comprehensive development plan, which precedes resource consent. This is where facilitation between various council departments and land developers is important.

Examples of clustered developments which respond to the natural or cultural landscape are shown in Figure 20.

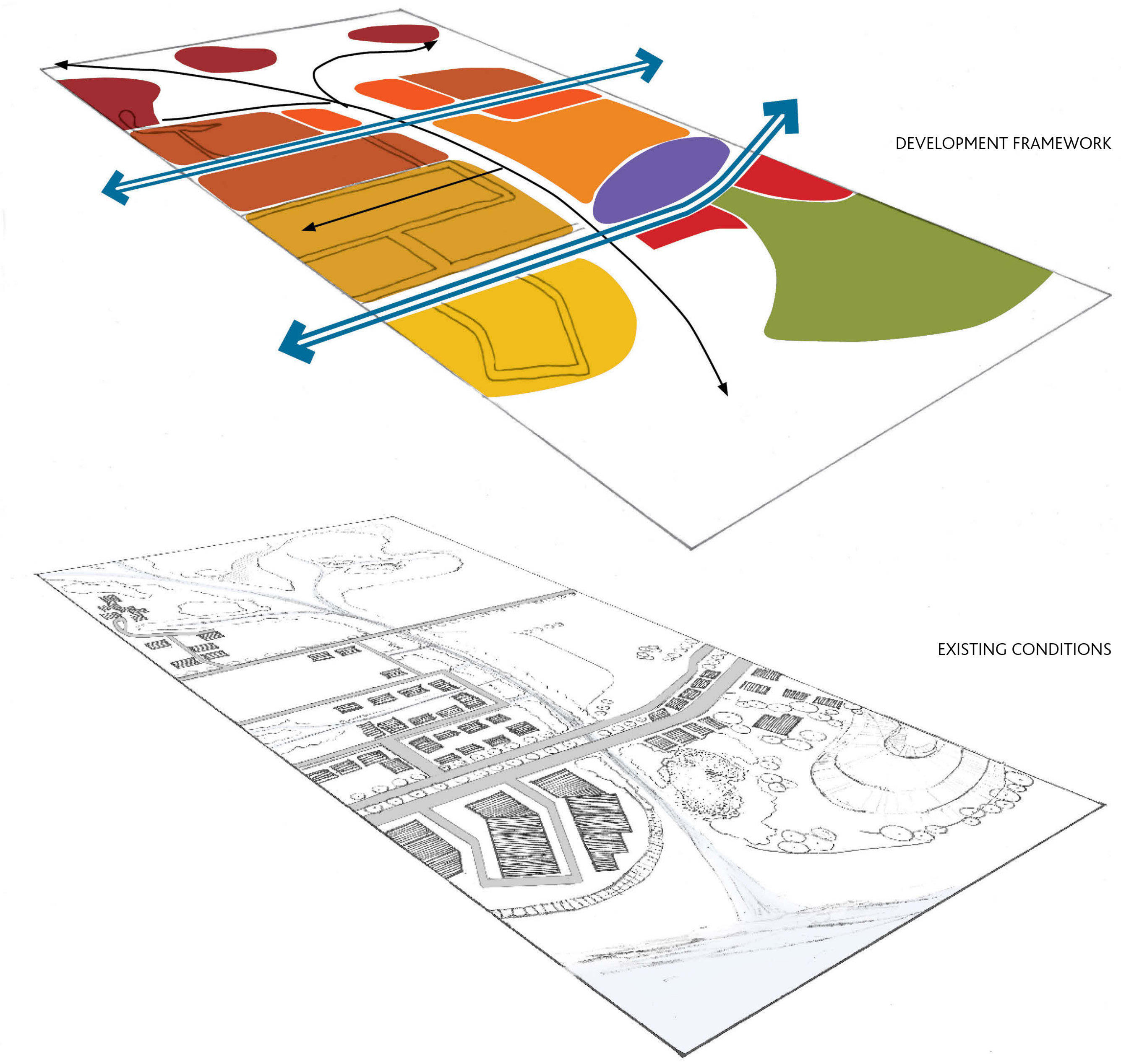


Figure 19: A development framework of proposed infrastructure and land use typologies

Figure 20: Above and overleaf, clustering in greenfield or rural environments responds to the natural and cultural landscape


Pupuke Rd
Kauri Glen Park
Recreation Drive
Birkenhead War Memorial Park
Scenic Reserve
Waratah St
Birkenhead Leisure
Birkenhead Ave
Zion Rd
Birkenhead
Onewa Rd
Northcote College
Highbury Bypass
Highbury Shopping Centre
Mokoia Rd
Video Ezy
Blitza Pizza
Birkenhead Library
Masala
Le Roys Bush
Hinemoa St
Thai Isaan Restaurant
Palmerston Rd
Rugby Rd
Eight Point Two

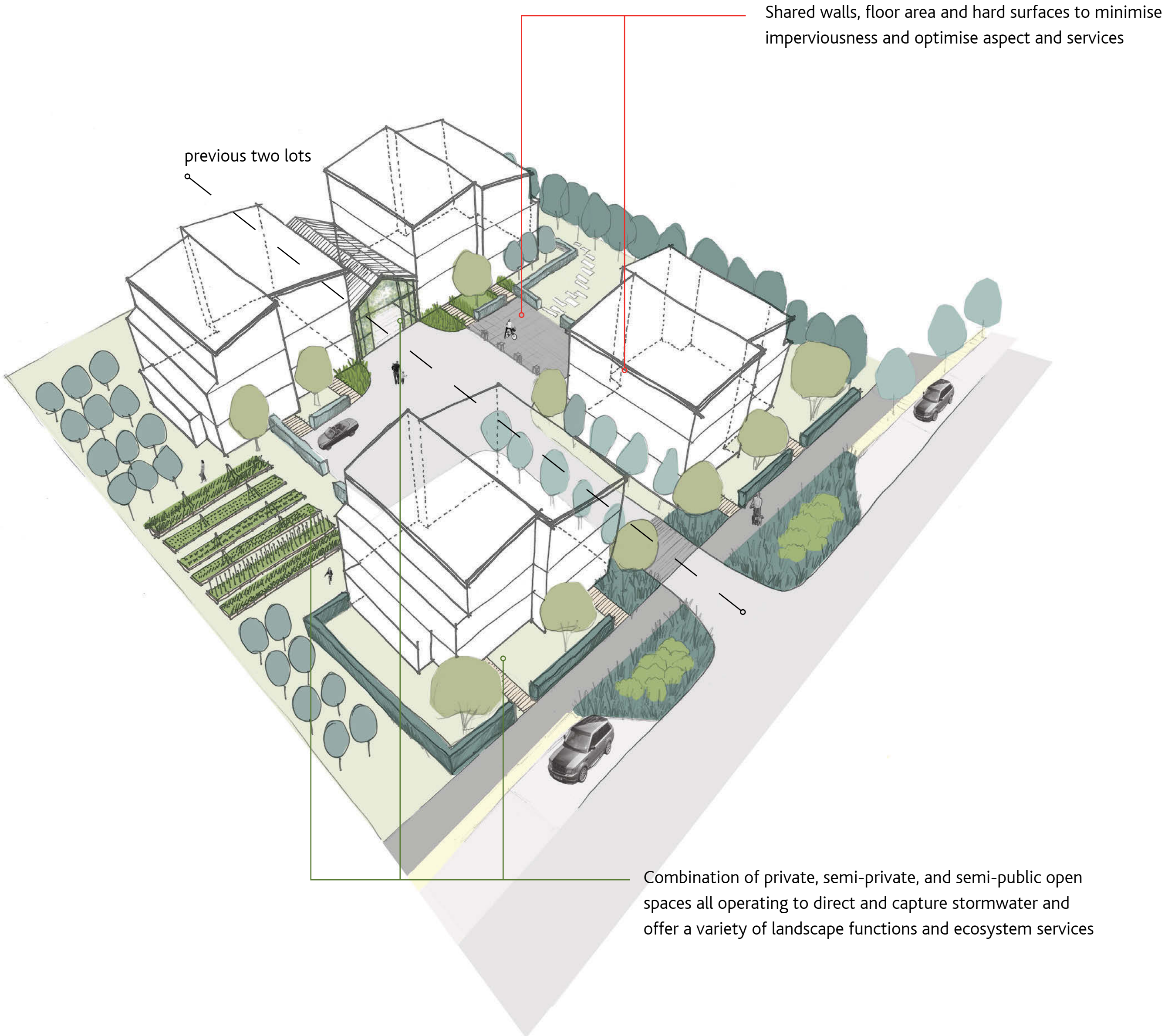


Figure 21: An example of infill redevelopment to achieve higher density, while additionally enhancing ecosystem services for the site

D4.2 Infill and brownfield development

Two common redevelopment scenarios are infill redevelopment, which increases the density within existing urban areas (refer to Figure 21), and adaptive re-use developments which modify existing buildings and infrastructure for contemporary use. Redevelopment utilises existing resources to reduce pressures on local infrastructure and direct development away from the region's hinterland. Redevelopment is also a means to create an enhanced environment for an existing site.

Recent public policy has called for increased affordable housing, higher density around public transport hubs, and the reinvention of areas such as ports of Auckland as a post-industrial waterfront. Redevelopment has also been driven by increased environmental standards relating to stormwater discharges, climate change and pollution prevention for existing activities.

The redevelopment of urban sites provides an additional set of challenges when compared to greenfield sites due to existing services and historic land uses. However, the principles of WSD and the design phases recommended here apply equally to brownfield and greenfield sites. WSD principles are presented below, with specific regard to brownfield redevelopment scenarios.

1. **Promote inter-disciplinary planning and design**
   Analyse the site for mixed use development opportunities, and the potential retrofit of environmental services. It is important to consider existing community stakeholders to ensure their concerns are adequately addressed and project viability is not compromised.
2. **Protect and enhance the value and function of natural ecosystems**
   Redevelopment provides the opportunity to redress existing effects of stormwater on the receiving environment, including groundwater from contaminated soils. The integration of 'green' and 'blue' infrastructure into a developed site provides increased opportunities for urban ecology and its associated ecosystem services.
3. **Address stormwater effects as close to source as possible**
   The redevelopment of a site may include retrofit of pervious paving and landscape areas, relocating buildings to allow shared infrastructure, or increasing the number of floors within the existing building footprint. It is important that opportunities for prevention as well as mitigation of stormwater are considered during the design process, including use of rain water, opportunities for infiltration, and below-ground detention technologies.
4. **Mimic natural systems and processes for stormwater management**
   The retrofit of a developed site does not preclude green infrastructure since living roofs, planter boxes and tree pits can all be incorporated into architecture or paved areas. The reconstruction of the site can also allow stormwater to be redirected to these treatments. The retrofit of multiple sites may also provide opportunities for centralised natural systems such as vegetated overland flow paths along boundaries and streets, or bioretention in shared open spaces.

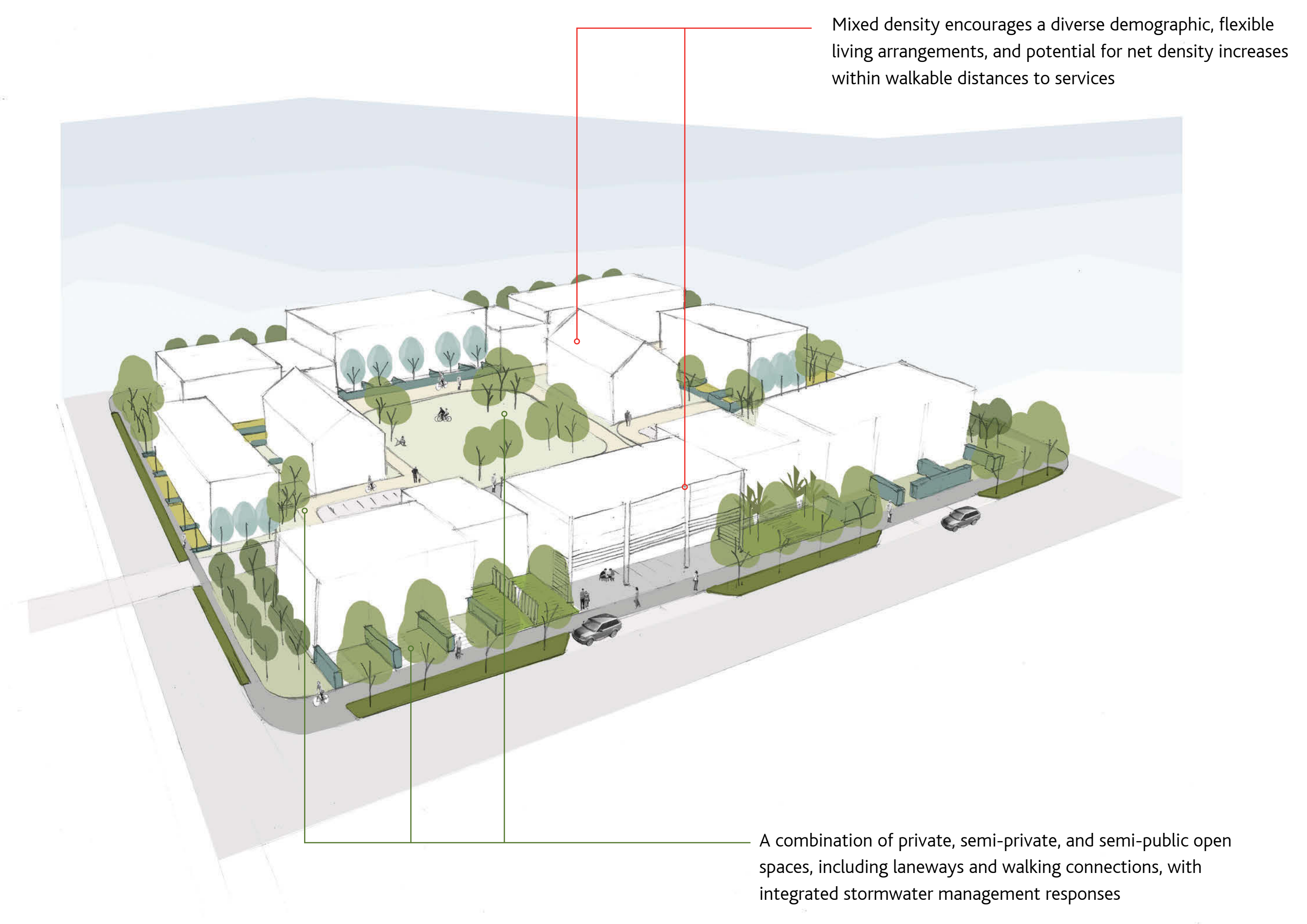


Figure 22: Mixed use development provides opportunities for increased density and diverse responses to stormwater management.

D4.3 Mixed use development

Mixed use communities are areas zoned for more than one activity, with a range of commercial and residential unit options (refer to Figure 22). They are a means to locate residents close to work and shops and are often located at public transportation hubs, further adding to the 'walkability' of these communities. The development of mixed use centres is a WSD approach operating at a catchment or regional scale, where flexible planning provisions have clustered activities near to existing infrastructure and away from areas of the hinterland or urban open space.

Mixed use development is only appropriate in some areas, and may be an anchor or transition for a broader single use zoning area. It is one of the responses available for the redevelopment of brownfield sites in the region, especially for post-industrial landscapes and logical growth nodes.

D5.0 Site context

In accordance with its definition, WSD "operates at the complementary scales of the region, the catchment, and the site". This involves the following steps as part of a comprehensive site analysis:

1. Review the relative values of a site's resources from a regional scale perspective
2. Consider a site's relationship with its contributing catchment and receiving environments
3. Ensure an appropriate site-specific WSD response in accordance with proposed land uses.

D5.1 The regional scale

The Auckland region is a diverse landscape of varying geologies, three significant harbours, abundant coastline, and flat lowland to steep upland environments. A site's location within the region should ultimately determine its developmental and environmental responses, including consideration of the following regional resources:

- Regionally significant ecosystems
- Receiving environment classifications
- Landscape typologies and sensitive landscapes from regional landscape assessments
- Protection of headwater and groundwater aquifers
- Regional flood management areas
- Productive soils
- Coastal inundation and storm surge effects
- Region-wide ecological linkages
- Open space frameworks
- Public transportation
- Regional growth and intensification nodes
- Combined sewer systems

The urban transect

An 'urban transect' is a planning method used to illustrate a change in urban density from the regional urban centre out to its hinterland. It is intended to ensure an appropriate transition of built form toward urban centres. It is also a means to consider relative bulk and layout of land uses, to provide for appropriate community character relative to a site's location within the region.

The urban transect is a means to express WSD approaches to support relative densities and specialised land uses (refer to Figure 23), including the following broad approaches:

- Increasing density near to stream corridors in suburban environments to capitalise on the value of these ecosystems as connected open space
- Buffering streams and other ecosystems where high density development is achievable and desirable
- The application of stormwater as a resource in civic centres or capture and re-use, to irrigate isolated landscape areas and to integrate as a dynamic element within the urban environment.

Figure 23: The 'urban transect' demonstrates an increase in urban activity and imperviousness, requiring a corresponding design approach for stormwater management and ecosystem services.

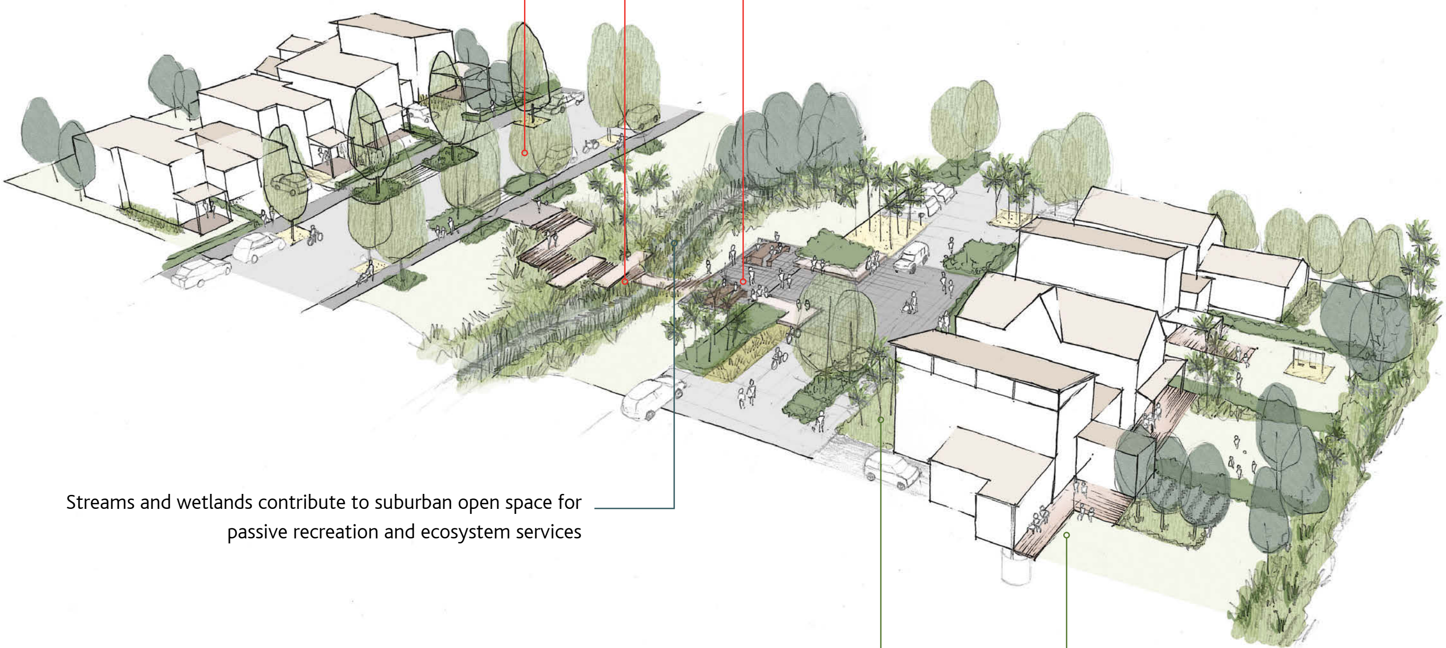


Figure 24: Suburban densities provide opportunities for enhanced environmental services in streetscapes and yards and the integration of streams and wetlands as community open spaces.

Rural landscapes

Conventional models of 'countryside living' are an inefficient use of productive landscapes, with individual house sites requiring significant amounts of infrastructure. Furthermore, it is difficult to justify public transport and other public amenities for low density areas. A more appropriate response to residential living outside the rural-urban boundary (RUB) is within rural town centres, or planned clustered developments that retain viable productive landscapes or ecological reserves.

Suburban residential

Suburban areas have traditionally been associated with unattached housing typologies with prescriptive lot layout and setbacks. WSD approaches require flexible planning rules to cluster built form and provide for more community open space and resilient natural systems (refer to Figure 24).

Riparian environments should remain open through low density residential areas to provide green and blue linkages from the hinterland to urban environments. This helps to provide ecosystem services, to increase residential amenity, and to ensure resilience of neighbourhoods from flooding by directing overland flow to natural floodplain areas. A significant challenge for WSD in suburban areas is to reconcile natural drainage patterns with road networks. This is discussed in more detail in the WSD street typologies that follow.

In addition to enhanced open space areas, suburban residential areas have less vehicle traffic and provide greater opportunities for streetscape amenity and green infrastructure. Larger private yards can also contribute to broader environmental frameworks and on-site stormwater treatment.

Figure 25: In more densely built areas, riparian areas and open spaces require designs that optimise stormwater management and ensure ecosystem resilience.

Urban residential

Higher density residential areas retain less natural environments and rely more greatly on capture and reuse of stormwater, and integrated green infrastructure such as raingardens, planter boxes and tree pits (refer to Figure 25). Where streams do occur, they are likely to be confined within a narrow environmental buffer that is designed with minimum environmental tolerances. Surface watercourses can also occur where there is acceptance of these features within roadways, laneways, and through open spaces.

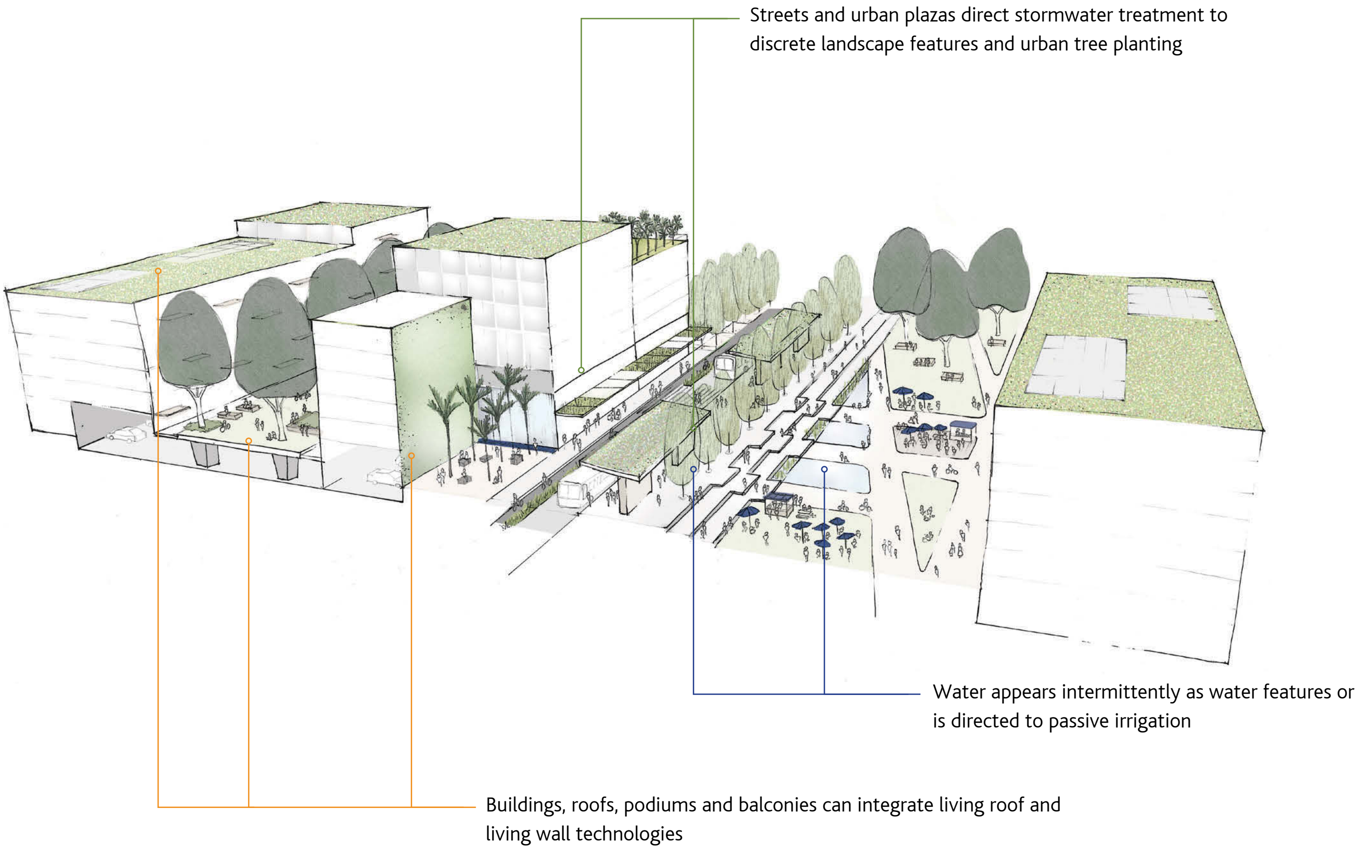


Figure 26: Water appears intermittently in the cityscape of civic or commercial centres and may often be detained underground, or captured and re-used in buildings.

Civic centres

The increased density and impervious surface area associated with civic centres generally results in fewer ecosystem services and increased stormwater flows and contaminants. It is therefore imperative to find design solutions that utilise the natural processes inherent in pervious paving, bioretention (raingardens and tree pits) and subsurface wetland technologies. There is also significant treatment potential available from trees in streets and plazas, where rainfall is captured in canopies and directed via stem flow or overland flows to tree pits.

Architecture can contribute significantly to stormwater management in urban areas, through living roofs, living walls and planted atriums. These contribute valuable urban open space, while potentially capturing and re-using rainfall for passive irrigation and cooling of buildings (refer to Figure 26).

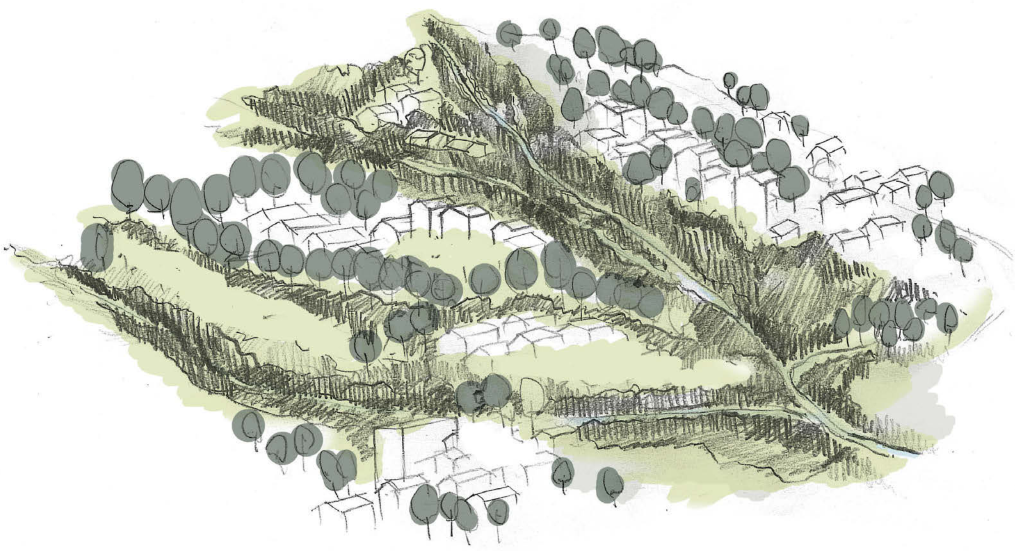
D5.2 The catchment scale

Before 2004, Auckland Council's Catchment Management Plans (CMPs) largely focused on stormwater network capacity. The advent of Integrated Catchment Management Plans (ICMPs) provided scope to focus on specific land use effects, and the relative values and sensitivities of receiving environments (Young & Heijs, 2010). A further change in terminology to Stormwater Management Plans (SMPs) has allowed these plans to address a variety of scales and is the current terminology used at Auckland Council.

SMPs are sometimes prepared in conjunction with 'structure' or 'comprehensive development' plans (CDP). These are spatially-based land use planning documents that take into account the ecological and hydrological gradients across the catchment to provide an appropriate development response, potentially including clustered and mixed use development approaches.

Some of the planning considerations at the catchment scale include:

- Remnant ecosystem and headwater protection
- Hazards and geotechnical constraints
- Developable aspect and slope
- Existing stormwater management functional areas such as floodplains and aquifers
- Stream buffers offering resilience to land use effects
- Stream corridors to accommodate stormwater management and open space functions
- Flood hazards and overland flow paths
- Regional ecosystem linkages
- Regional infrastructure connections
- Regional growth planning and urban design objectives
- Coastal management



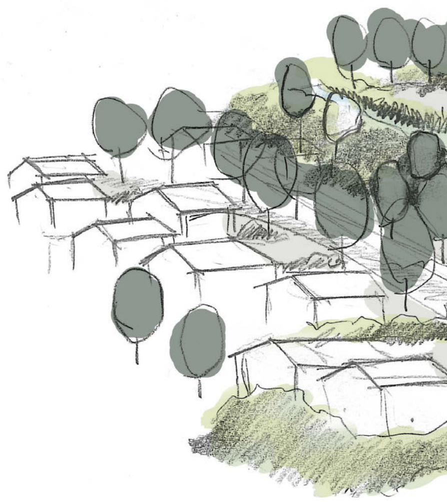


Figure 27: Variation in stormwater management responses relative to catchment position and/or slope

Catchment headwaters

Headwater environments make up a significant proportion of Auckland's land area, due to the prevalence of low order streams and intermittent gullies within the region. The steep and intermittent nature of these streams requires vegetation to protect against erosion and to attenuate stormwater runoff to prevent it rapidly concentrating in overland flow paths.

Stormwater management in the upper catchment is often associated with source control, including capture and re-use of rainwater, or retention and treatment in bioretention practices. Groundwater infiltration is also a relevant stormwater management response within Auckland's volcanic fields. Auckland is fortunate to have retained open space associated with many of its volcanic cones, which protects steep slopes and aquifer recharge areas.

The steep nature of headwaters, as well as the need for resource protection, lends itself to a clustered form of urban development, where dense residential or institutional buildings are dominated by planted slopes and generous open space (refer to Figure 27). In rural areas, woodlots and other longer term productive landscapes may be an appropriate response to steeper slopes.

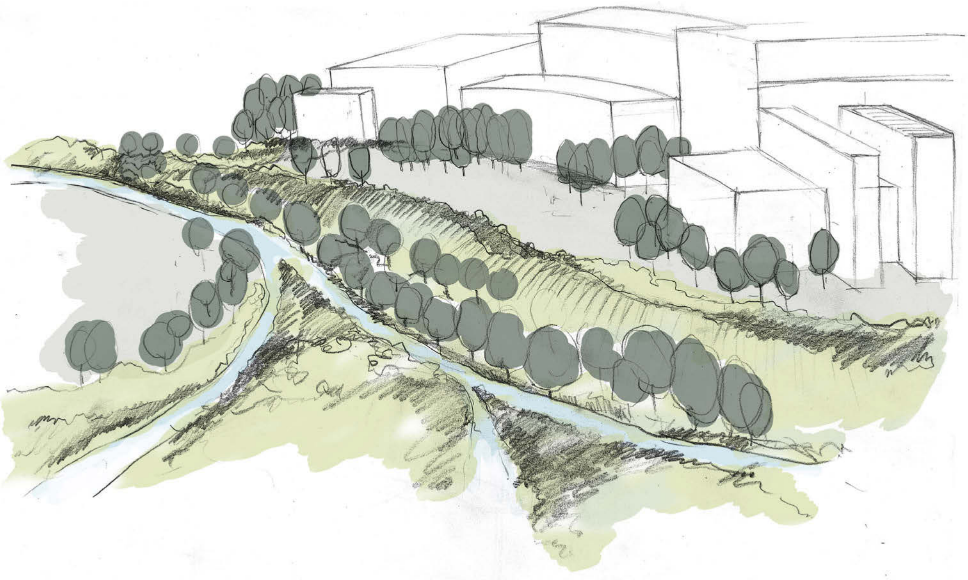
Mid catchment

The mid catchment is generally associated with rolling slopes where stormwater runoff coalesces into larger stream and wetland systems. These riparian systems require the protection of planted buffers and appropriate land management. This protects the natural drainage patterns through the mid slopes and upper valleys of urban environments, which can provide important open space connections along low valley gradients.

Stream and wetland widths can vary according to adjacent land use, with thick vegetation supporting narrow stream corridors in dense urban areas, and wider and more open floodplain environments in suburban neighbourhoods allowing for a combination of diverse riparian habitats and open space opportunities.

MID CATCHMENT - Managing riparian corridors

LOWER CATCHMENT - Flood management



Lowland and coastal environments

The primary WSD issues in the lower catchment are protection of coastal and estuarine environments, and the prevention of flooding impacts. In terms of urban form, lowland environments are usually undulating to flat areas, which provide optimal site conditions for large scale, dense and specialised urban typologies such as commercial centres, ports and industrial zones.

The resulting land use pattern is a contrasting environment between the built form and open spaces. Wide open spaces in association with floodplains, estuaries and recreational open space sit directly beside dense development or industrial and commercial precincts.

Flat environments often require widely distributed WSD responses such as raingardens and swales. Wetland environments are also common in flat environments, where they can accommodate surface flooding and high groundwater levels.

Careful planning is required to minimise environmental impacts for greenfield situations, and to provide remediation of ecosystems if brownfield development opportunities arise.

Reconciling the urban grid

Urban design principles, discussed previously in Section A, promote a grid-like street pattern to provide for greater community connectivity, traffic dispersal and wayfinding. However, there is inevitably a creative tension between the dendritic pattern of natural stream systems and the rigid street patterns of urban form. The means to reconcile these patterns occurs at the fundamental level of movement within the site. It is a matter of interlacing natural and built elements in the most appropriate ways to rationalise objectives for each system. Some potential responses may include (illustrated in Figure 28):

- Adapting the urban street grid pattern in response to existing topography and landform
- Creating 'naturalised' drainage patterns to receive runoff from increased imperviousness, placed along boundaries and within streetscapes
- Allowing flexibility for both road carriage width and riparian buffers
- At strategic stream crossing points, favouring pedestrian and bike crossings over roads
- Assisting vehicle movements by prioritising street connections and potential stream crossings based on neighbourhood density and travel distances
- Creating streetscapes and street alignments which draw from and extend riparian open spaces
- Increasing neighbourhood cycle/pedestrian connections through stormwater reserves
- Mitigating the occupation of the floodplain by road crossings by enhancing stream habitats elsewhere (internal to blocks)
- Providing for wider stream corridors at road crossings to accommodate bridge abutments, landscape transitions, and habitat refuges above and below culverts.

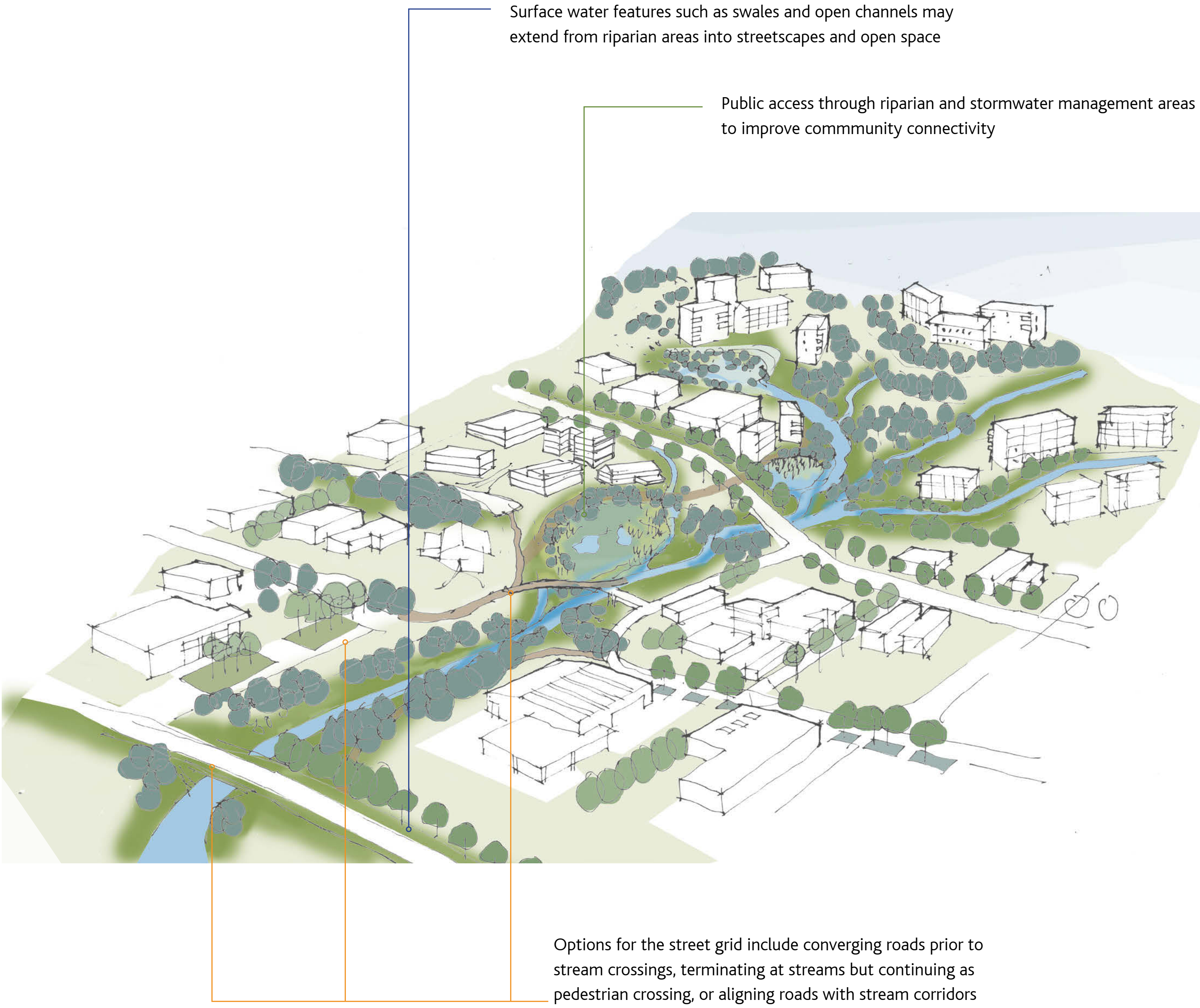


Figure 28: Balancing elements of the connective urban street grid with existing natural drainage patterns and enhanced ecosystem systems

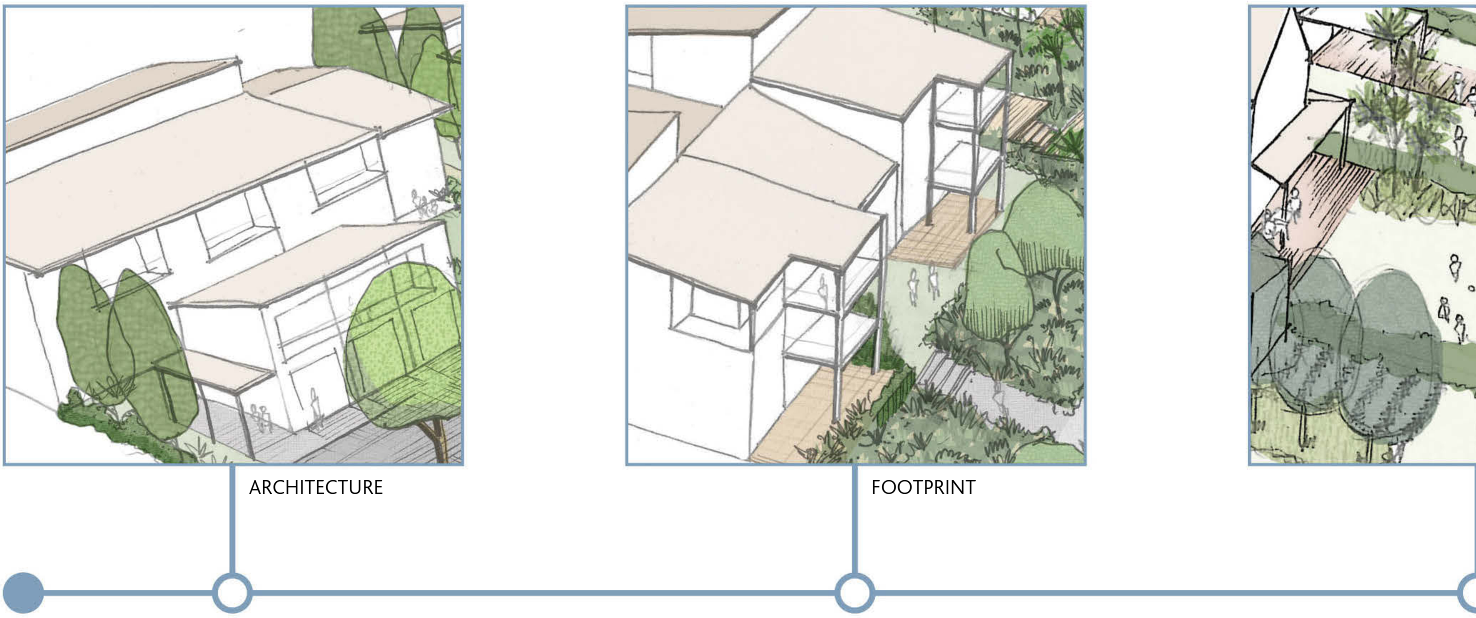


Figure 29: Stormwater management responses from private to public spaces across the site

D5.3 The site scale

A site layout comprises a number of elements that make up the public and private domain, as shown in Figure 29. These include the building, the landscape yard, the street and the open space. WSD principles can be applied to each of these elements.

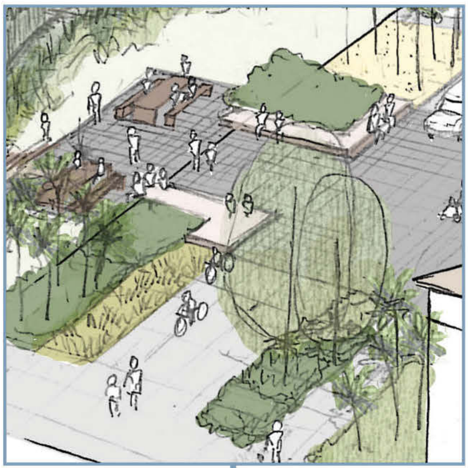
The private lot

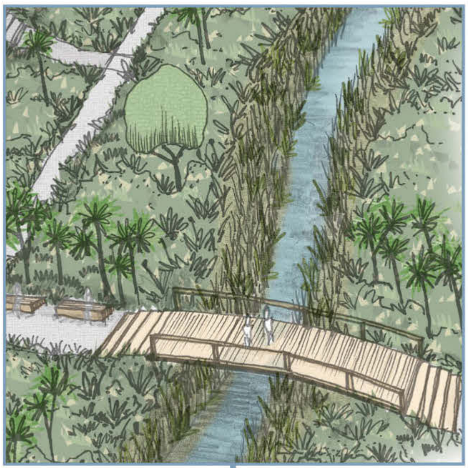
Architecture and footprint

The following WSD treatment approaches can be applied within the footprint of buildings and structures:

- Combine the footprints of garages, utilities and ancillary structures to reduce impervious surfaces
- Provide an architectural response to slopes and vulnerable soils, e.g. pole or terraced housing which limits the earthworks required to accommodate the building
- Provide for flexible internal layouts of attached or semi-attached housing typologies to provide for diverse family groups and increased occupancy across land area
- Capture stormwater for re-use in buildings
- Use inert materials for construction that will not contribute contaminants to stormwater
- Consider living roofs, living walls and planter boxes to attenuate and treat stormwater.


YARD


STREET


OPEN SPACE

Yard

The yard can be a useable open space or a buffer to adjacent land use. It may include private, semi-private, or communally operated areas. Yards can receive stormwater runoff as passive irrigation and contribute to stormwater management in the following ways:

- Share driveways between house lots to reduce impervious areas
- Utilise pervious paving options for drives and paths, and direct stormwater runoff from these surfaces to landscape areas
- Direct overflow from raintanks to purpose-built landscape areas as passive irrigation
- Utilise hedges, swales or filter strips to define boundaries
- Buffer existing natural areas
- Minimise fertiliser and pesticide inputs for landscape maintenance
- Investigate 'no mow' options using native plant substitutes
- Investigate the potential for communal overland flow paths, or even small streams across neighbouring yards
- Use tree planting to define boundaries, as summer shade, or to moderate prevailing winds, while also contributing a stormwater management function
- Investigate opportunities to direct stormwater runoff to raingardens and infiltration basins.

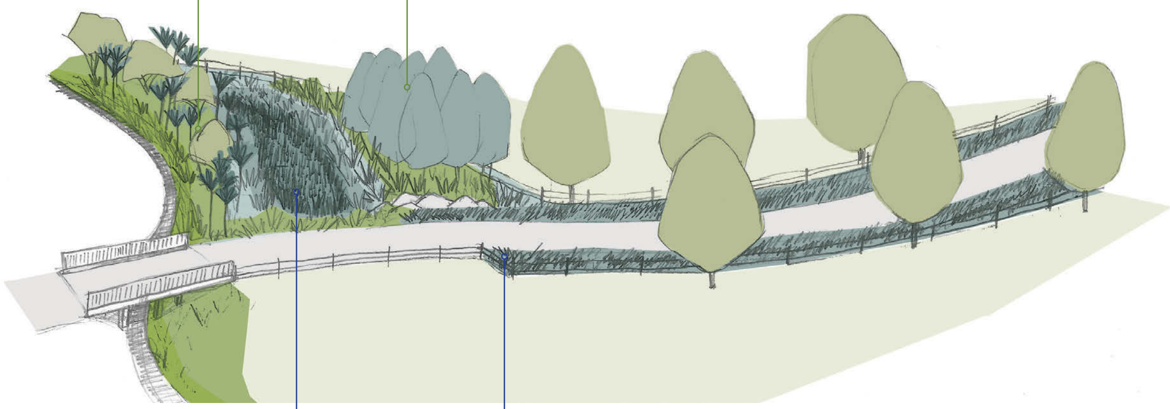


Figure 30: An example of passive treatment of stormwater within the rural landscape

WSD streets

WSD approaches can re-invent the function of streets in our communities to be lineal open spaces, pedestrian friendly environments and living ecosystems. Directing stormwater runoff to street trees and landscape berms not only delivers at-source treatment of stormwater runoff, it also irrigates and fertilises these plants.

The design of 'living street' environments can incorporate aspects of development such as stormwater management requirements, roading hierarchy, priority of transport mode, neighbourhood character and intersecting natural systems. For all WSD treatments, safety should be considered for street environments, including visibility for cars and pedestrians, response to road speeds, and 'turn off' areas for cyclists and pedestrians to escape erratic drivers.

Rural roads

Rural roads usually have increased speeds and less provision for amenity planting. However, there is still potential to enhance planting of swales and filter strips to reduce erosion and sediment entrainment. Parallel wetland systems can be located at the intersection of swales and stream environments to reduce instream erosion and provide further stormwater treatment (refer to Figure 30).

Production tree species can be included alongside swales or encouraged on adjacent boundaries to intercept rainfall, treat nitrogen in groundwater, and provide partial shade. However, tree planting alongside roads should allow for sunlight to pass through in order to foster plant growth in swales and to reduce the likelihood of frost on road surfaces.

Park streets

Park streets refer to street environments that are integrated with adjacent open space areas, including stream corridors and wetlands. Park streets generally have a higher landscape amenity that can allow for appropriate vegetated WSD approaches.

Figure 31: Laneways combine pedestrian and automobile surfaces, providing primary treatment of stormwater and operating as overland flow paths.

Laneways and pedestrian-oriented communities

There are examples of traffic-free communities in New Zealand and overseas, where car parking is placed outside of planned communities and generous access is provided for pedestrians and cycles. Another model is a pedestrian-oriented network where pedestrians and cyclists have priority access along building fronts where there are no driveways, while short feeder lanes provide automobile access at the back of houses.

These back lanes are often shared surfaces (with access for both pedestrians and automobiles) that act as semi-private spaces to connect residents within a block (refer to Figure 31). From a WSD perspective a low traffic laneway provides opportunities for pervious paving, above ground detention and overland flow to landscape areas. By removing parking from the front street, it reduces driveways and the carriageway on main roads, providing for more cycleways, street trees and landscape areas.

Industrial subdivisions

Roadways in industrial areas are often very wide to accommodate both extended carriageways and landscape berms. These streets may have sufficient space to accommodate open channels or lineal wetlands. WSD elements can be incorporated into berms or combined with landscape yards of individual lots.

Open channels provide the equivalent ecological function of intermittent streams, which are often lost to accommodate industrial lots. These watercourses can provide for increased flow capacity to reduce flooding risk. Vegetated stormwater features in general can play a part in a spill response, to capture and isolate contaminants before they reach the reticulated network and the receiving environment.

The installation of swales or lineal raingardens in industrial roads must accommodate turning circles for larger vehicles. These can be reduced through shared access points and internal private through-roads (refer to Figure 35). Internal road systems between industrial blocks can reduce traffic circulation requirements for individual lots, which can remove impervious surface requirements and optimise useable land area.

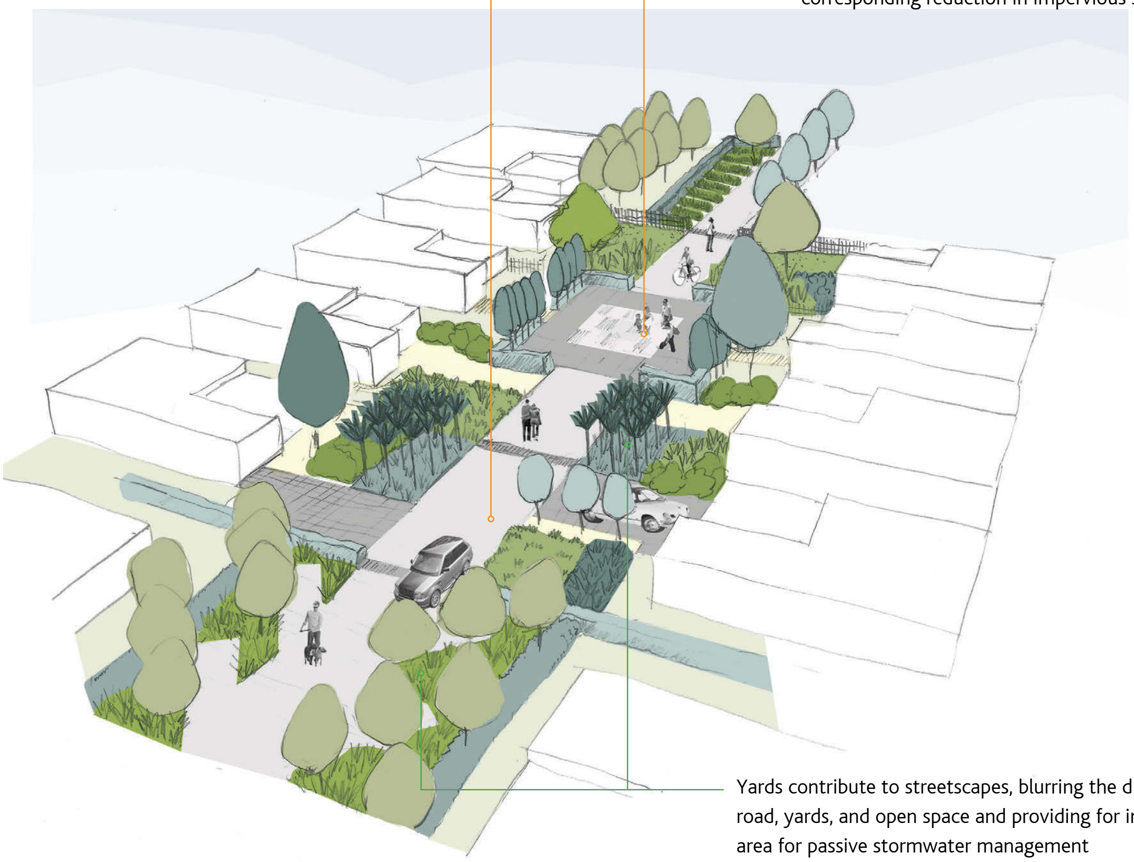


Figure 32: Garden streets blur the distinction between private yards, streets, and open space to form significant streetscape amenity and stormwater treatment opportunities.

Garden streets / homezones

These streets, with the equivalent traffic movements of a 'neighbourhood' street, intentionally blur the distinction between streets, open spaces and private yards (refer to Figure 32). Ownership and management of the areas must be agreed between public and private entities. There is significant potential to integrate WSD stormwater responses into garden streets, including the following measures:

- Combine automobile and pedestrian movement on the carriageway as a cue for lower speeds and to increase landscape areas in place of footpaths
- Redirect or 'choke' the carriageway at specific junctures to slow traffic by increasing the extent of landscape elements, such as raingardens or street trees
- Extend streetscapes across private lots and public open space to blur the distinction between roads and neighbourhood. This provides opportunities to retain existing vegetation and landform features as part of the roading corridor.
- Provide shared surfaces where the road is a single kerb-less plane (described in further detail opposite). This requires the redirection of stormwater to multiple landscape features or pervious areas, since kerb and gutter systems are no longer applicable.
- Provide for diffuse stormwater flows to landscape areas to allow passive irrigation
- Provide overland flow paths contained within landscape areas and away from carriageways.

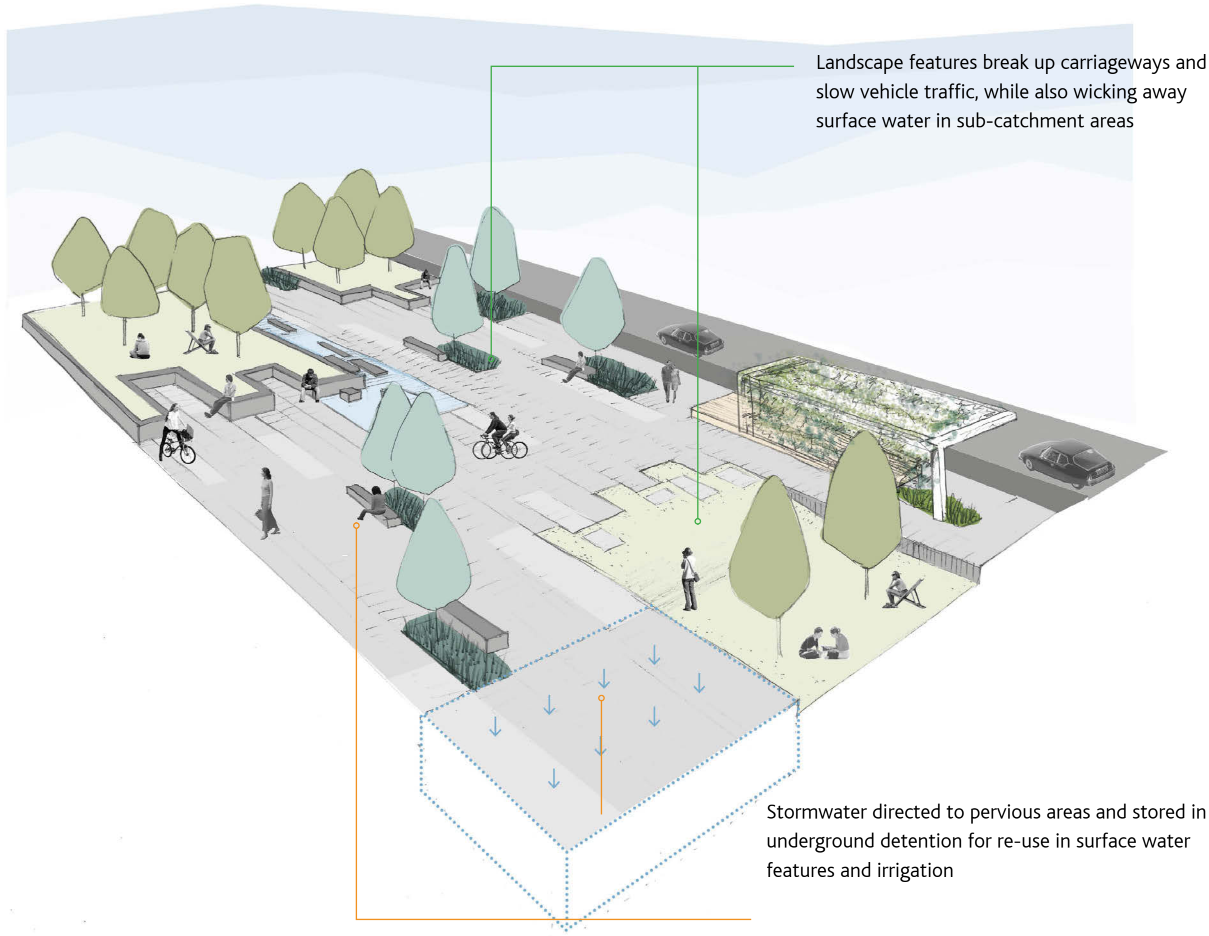


Figure 33: Shared surfaces integrating pedestrian and vehicle movement

Shared space

Shared space environments remove conventional traffic elements such as kerbs to re-prioritise pedestrians above vehicle movement. This may be accomplished in a number of ways, but generally these environments remove the visual cues defining a carriageway such as grade changes, signs, bollards, road markings and lineal berms in order to redirect driver behaviour.

The concept of shared space is based on civility and equitable use of public open space by all users. Shared spaces create an environment that encourages all users to think responsibly about the needs of others. Shared spaces generally function in street environments with less than 150 cars per hour at peak times (Boffa Miskell, 2010).

Shared space provides an opportunity for pedestrians to engage with a wider public realm and a unified space. In this way shared surfaces can be utilised for recreation and gathering. In combination with the removal of kerb and gutter systems, a WSD response is to direct stormwater to multiple landscape features or pervious areas for treatment and/or passive irrigation (refer to Figure 33).

WSD integration with open space

Public open space areas can act as default stormwater management areas by receiving stormwater runoff from adjacent impervious surfaces, as illustrated in Figure 34. Consideration needs to be given to the impact stormwater management structures can have on the amenity and values of the open space and its users. Stormwater reserves should provide the other functions of open space such as natural habitat, public amenity and recreation opportunities.

Combining public open space and stormwater function requires an integrated design approach between asset groups, community stakeholders, and operation and maintenance personnel. Some key considerations are provided below:

- Grade open spaces to allow recreation as well as stormwater attenuation/detention
- Provide pathways with appropriate width, cross slopes and drainage
- Keep structures above the 100 year ARI flood event for safety and to prevent water damage
- Limit the stormwater detention function of formal activity areas to less than 24 hours for a 2 year ARI event
- Design stormwater features that provide for landscape amenity, natural character values, social interaction and education/interpretation as appropriate
- Provide physical and/or visual access as appropriate to natural wetland environments and constructed stormwater features. Integrate with maintenance access where possible.
- Design stormwater management features to augment and/or buffer existing ecosystem functions and values
- Promote biodiversity from wetland to upland environments
- Include WSD responses to hard surfaces and structures such as car parking
- Design swales and watercourses so that they resist erosion and minimise maintenance requirements
- Where overland flow paths are accessible to the public (roads and pedestrian routes) AC CoP specifies a minimum depth of 200 mm and a maximum velocity of 0.6 m/s (see CoP 4.3.5.6).
- Rehabilitate soils and increase regenerating vegetation within open spaces to enhance stormwater attenuation potential
- Optimise the potential for stormwater and its entrained nutrients to be used as passive irrigation for open space planting
- Ensure maintenance regimes avoid close mowing for all areas, and place controls on the application of fertilisers, pesticides and herbicides
- Seek to connect discreet and separated open space areas within a community by linking through covenanted private land and/or 'living street' environments.

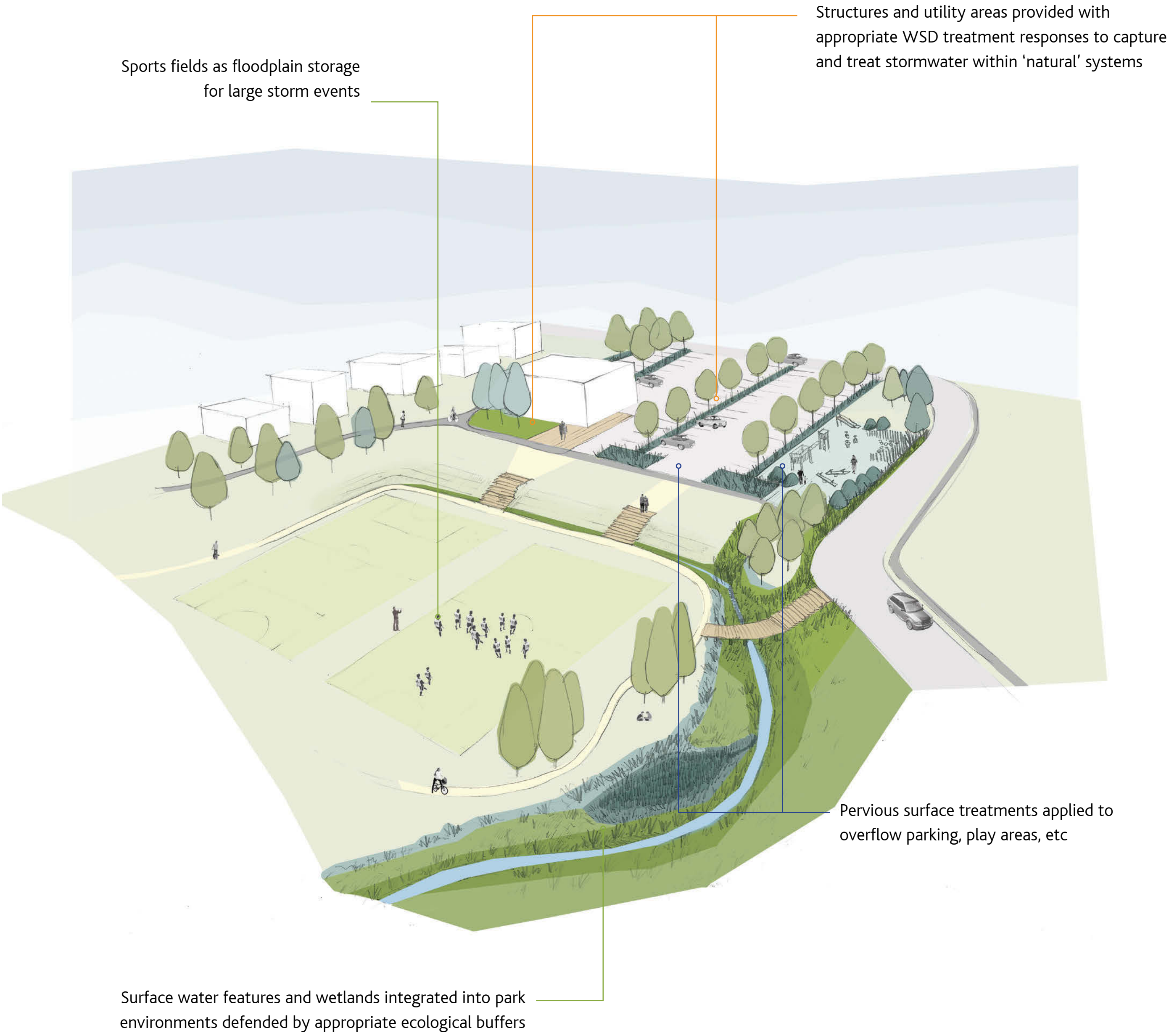


Figure 34: Open spaces can provide enhanced stormwater management functions, while also acting as default storage to detain larger storm events.

Industrial and contaminated sites

Contamination of soils can occur as a result of agricultural chemicals, industrial processing, vehicle use, storing of hazardous substances, dumping, and migration of contaminants from off-site. Where contaminants are present in the soil or groundwater, the risks may include short-term toxicity, long-term bioaccumulation by plants and animals, or unpredictable synergistic effects in the environment. In these instances, monitoring at variable groundwater levels and at various locations should be undertaken to determine whether to cap, export or phytoremediate contaminants.

In a site that is storing or using contaminants of concern, the potential source should be isolated through rain cover or similar, and any stormwater runoff generated should be separated either to an appropriate discharge location, or to storage for re-use in industrial processes. Part of stormwater management in this instance is appropriate pollution prevention and spill response plans.

Decentralised and discrete stormwater treatment practices such as gross pollutant traps, sand filters, swales or raingardens are appropriate to allow for localised spill containment without disabling wider stormwater systems. The separation of an industrial site into multiple sub-catchments also offers site flexibility for future tenants of the site.

Impervious surfaces are significant in industrial sites. However, the efficient use of impervious surfaces in industrial precincts can be provided by shared kerb breaks from main roads to increase landscape berms, and shared internal roads around buildings and between blocks to reduce turn-around requirements and increase available building footprints and staging areas (refer to Figure 35). Stormwater treatment practices such as swales or wetlands can also be shared across common boundaries.

A large volume of stormwater is available for capture and re-use in industrial sites, from large roof and paved areas. Alternatively, frame construction can be strengthened for 'extensive' living roof or living wall technologies. This might include a strip of planting on a strengthened area of rooftop to treat the first flush of contaminants, or brown roof technologies such as xeroscapes (arid, low soil plant systems).

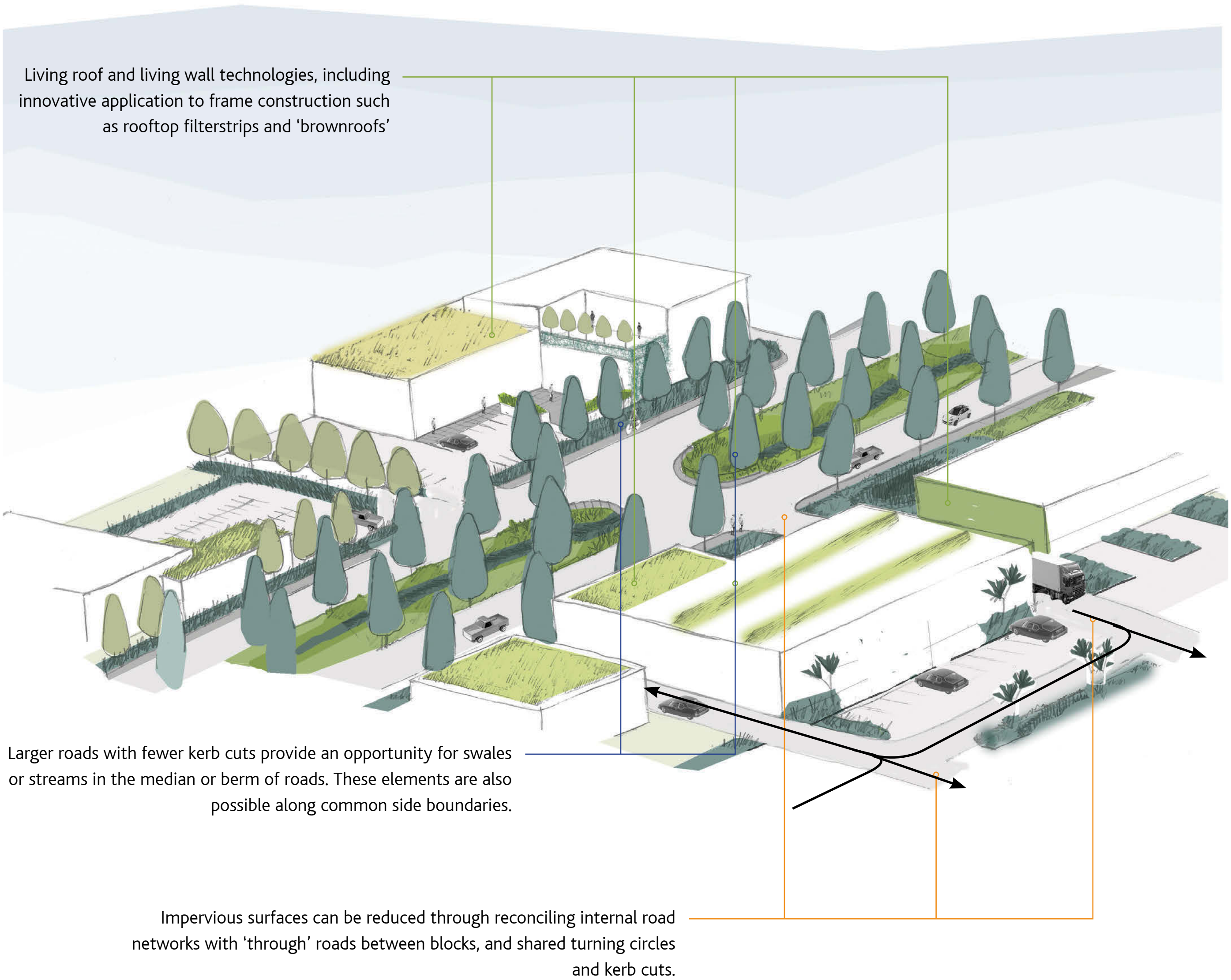


Figure 35: The industrial scale provides opportunities for large scale landscape responses, shared infrastructure, and targeted sub-catchment responses.

SECTION E: CONCEPT DESIGN

Clearwater Golf Resort, Christchurch

Lion Breweries, East Tamaki, Auckland

E1.0 Concept design phase planning

The Concept Design phase draws on the Site Analysis phase to develop a feasible concept design. This phase will also assess the requirements for stormwater detention, water quality treatment and flood mitigation for a site. A concept design will indicate how all stormwater objectives are met through single responses or through a combination of approaches as part of a treatment train (discussed below).

During the Concept Design phase, a pre-application meeting with regulatory authorities can be helpful in order to discuss potential WSD approaches, consider integrated consents, and provide the framework for best practicable option (BPO) decision-making.

E2.0 Stormwater treatment train

A stormwater treatment train is the combination of sequential stormwater management responses that collectively deliver stormwater quality and quantity objectives for a site. The treatment train is based on a logical sequence of stormwater flowing through a catchment, beginning with stormwater runoff controls at-source, followed by capture and treatment of overland flows, and finally the enhancement of receiving environments to enhance their stormwater management function.

The concept design takes the development form and adds sufficient detail to ensure the design is feasible and to allow an initial cost estimate to be prepared. The concept design should provide a sufficient level of detail for plan change applications if required.

Note: Technical design guide documents provide detailed advice for design and construction of devices.

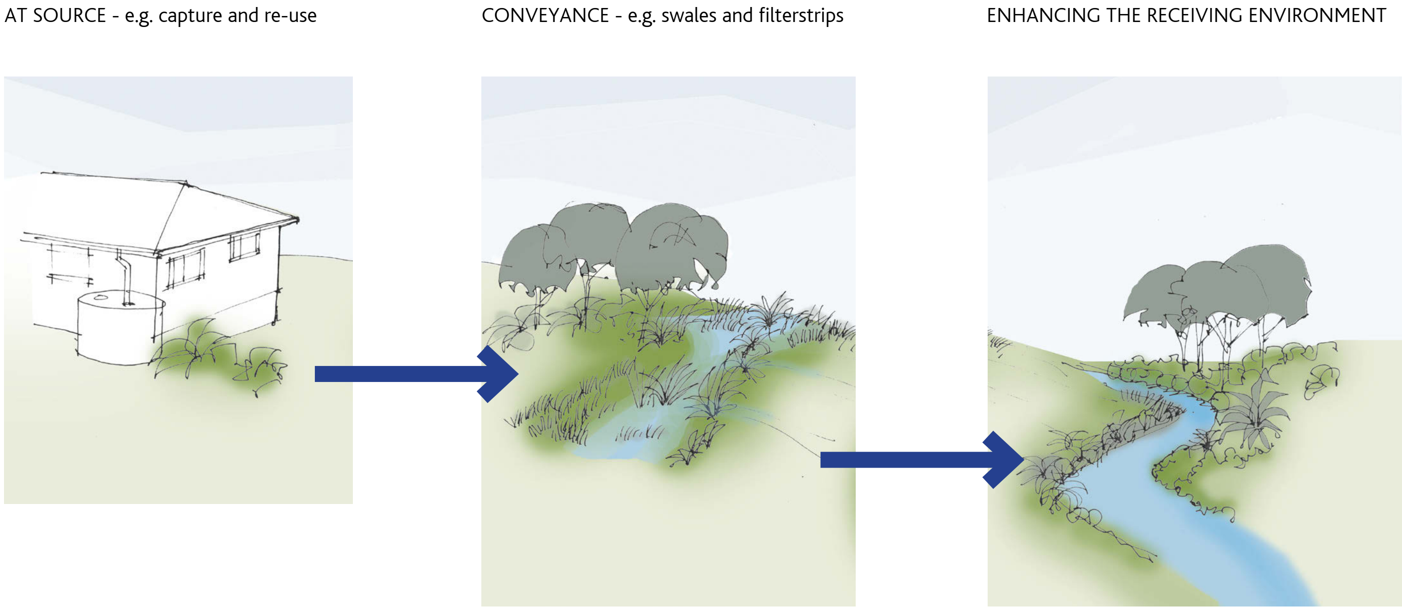


Figure 36: The stormwater treatment train slows, attenuates and detains stormwater volumes through longer and 'rougher' flowpaths in the catchment.

E2.1 Stormwater quantity

Increases in stormwater runoff volumes associated with land development can put significant stressors on receiving environments. In order to avoid potential adverse effects, concept designs for a site should seek to direct stormwater flows through a series of mitigation practices, all of which contribute to the retention, attenuation or infiltration of a component of stormwater volume (refer to Figure 36). This will prevent the rapid accumulation or superposition of peak flows at the bottom of the catchment. Refer to Section B2.0 for a discussion of peak flows.

A WSD approach increases the 'initial loss' of rainfall through a preference for pervious surfaces, restoration of forested conditions, and rehabilitation of soils in the catchment. Concept designs can also directly cater for stormwater volumes through directing runoff to landscape areas, raingardens or wetlands for retention or detention. For more information, please refer to Auckland Council Technical Report TR2013/035 *Auckland Unitary Plan Stormwater Management Provisions: Technical Basis of Contaminant and Volume Management Requirements*.

WSD approaches also influence the time of concentration of stormwater flows within a catchment. The primary factors affecting the time of concentration include the saturation of soils, and the length, slope and roughness of flow paths. Conventional developments often utilise kerb, gutter and reticulated systems, which rapidly concentrate flows to the point of discharge. WSD approaches promote dispersed flows across landscape areas or vegetated swales that are rough rather than smooth. This decreases velocities of stormwater flows in the catchment, slowing the time of concentration, and subsequently reducing the peak flow duration.

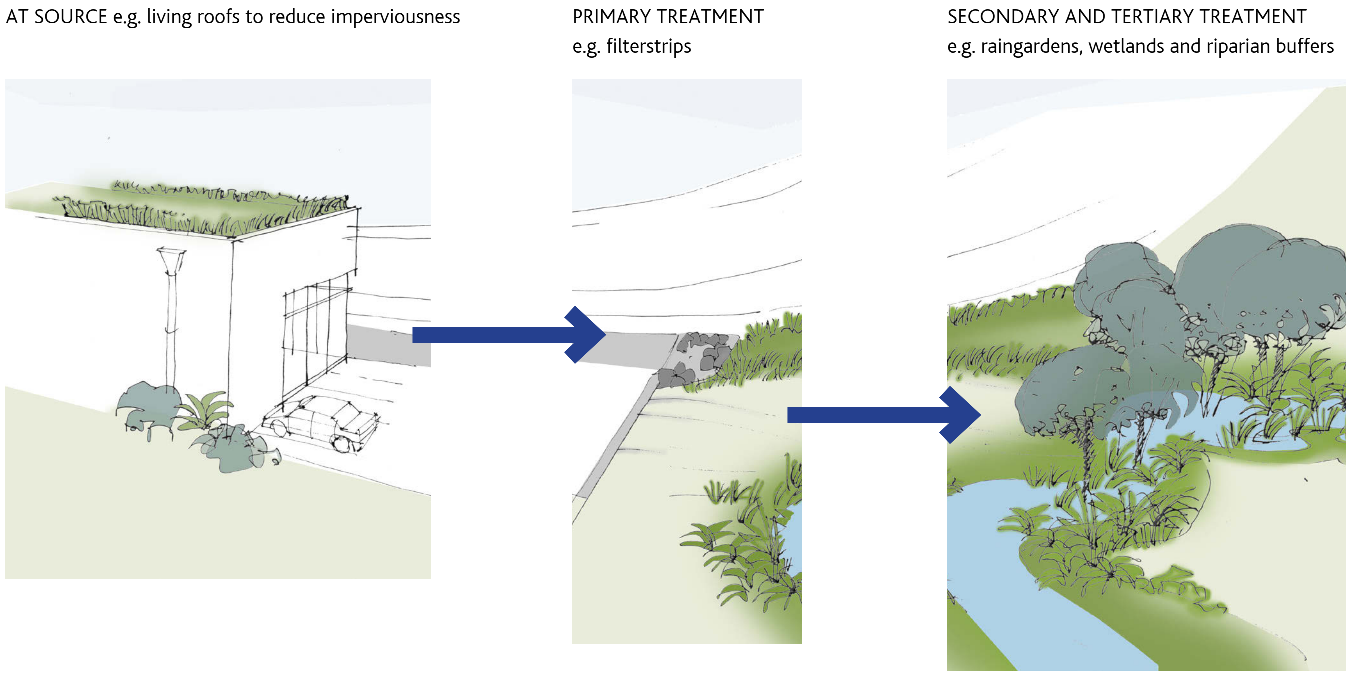


Figure 37: The stormwater treatment train removes contaminants in a sequence of complementary systems.

E2.2 Water quality

A treatment train approach enables the capture of a range of predicted contaminants by directing stormwater runoff through a complementary sequence of stormwater management responses (refer Figure 37). For example, a roadside swale might capture gross contaminants and fine gravels in stormwater runoff, which could then be directed to a raingarden to capture fine sediments and hydrocarbons.

Many Auckland catchments generally contribute fine sediments of Waitemata group silts and clays into stormwater runoff. Additional contaminants of concern are heavy metals entering estuarine and harbour environments such as copper, zinc and cadmium. For more information, please refer to Auckland Council Technical Report TR2013/035 *Auckland Unitary Plan Stormwater Management Provisions: Technical Basis of Contaminant and Volume Management Requirements*.

WSD promotes the direction of stormwater runoff to enhanced natural systems or practices that incorporate natural processes, such as raingardens and swales. The capture of fine particles and contaminants occurs at the plant-soil-water interface where they are captured, metabolised and transformed through physical, chemical and biological processes. The treatment processes inherent to natural systems are described in more detail in Auckland Regional Council Technical Report TR2009/083 *Landscape and Ecology Values within Stormwater Management* (Lewis et al., 2010).

The treatment potential of natural systems and processes can be optimised by incorporating the following approaches (discussed in the following relevant descriptions of treatment types):

- Increase hydraulic residence time and provide a low-turbulence environment in practices incorporating natural systems
- Use medium to coarse textured soils for enhanced permeability
- Provide dense planting of fine leaved plant species to maximise filtering potential and prevent preferential flowpaths
- Provide a neutral pH to create the aerobic and anaerobic conditions for cycling nitrogen, sulphur, etc.
- Raise organic content, soil exchange capacity, and provide for a neutral pH in order to precipitate metals
- Ensure a high soil-water-plant root interface for phosphorus uptake.

Potential contaminant sources

A treatment train should be selected from a suite of potential stormwater management responses in order to target specific land use contaminants (refer to Figure 38). Some of the more common land uses and their associated contaminants are discussed below.

Residential developments commonly contribute fine sediments, nutrients, pathogens and general organics to stormwater runoff. Landscape areas also contribute pesticides, herbicides and organic debris such as displaced mulch and grass clippings. Zinc and copper can commonly occur in stormwater runoff from building roofs and spouting, and fertilisers and fungicides (Kennedy & Sutherland, 2008).

The contaminant load from streets and highways is impacted by automobile behaviour (stopping and turning), and this increases with vehicle counts (Shaver, 2010a). Sediments and associated contaminants stem from pavement abrasion, car wheels and atmospheric deposition. Engine wear and emissions contribute to a lesser degree. Contaminants specific to transport infrastructure include hydrocarbons and heavy metals from wearing of parts, fuel and lubricants.

Industry contributes common urban contaminants as well as higher concentrations of less common and potentially toxic contaminants depending on the activity. Sources of contaminants include structures, roofing and spouting, vehicle and waste storage, and stockpiles. Improperly connected sewer pipes and drains may lead to contamination of groundwater or increased combined sewer overflow events. Large areas of impervious surfaces can also lead to spikes in water temperature in stormwater runoff, which can elevate the toxicity of other contaminants.

	CONTAMINANT				TREATMENT RESPONSE						
Contaminants	Particle size		Associated sediments	Treatment process	Gross pollutant trapping	Sedimentation (pond & basins)	Filtration (swale & filter strips)	Constructed wetlands	Bioretention	Infiltration	Subsurface wetland
Sediment litter organics	>5 mm	**Particulates**	Gravels	Screening							
Fine sediment Suspended sediment Particulate metals Hydrocarbons Organic films	125 µm - 5 mm		Fine gravel to sand	Sedimentation							
	10 - 125 µm		Sand to fine silt	Sedimentation Filtration and adhesion							
Soluble organics Nutrients Pesticides Pathogens	0.45 - 10 µm	**Soluble**	Fine silt to fine clays								
	<0.45 µm		Very fine clays	Micro-biological and chemical							

Figure 38: The targeted treatment of stormwater contaminants through complementary practices (adapted from Eadie et al., 2009)


Great Barrier Island, Auckland

E3.0 Source control

Source controls seek to minimise the generation of stormwater runoff and its associated contaminants. The reduction in runoff can be achieved through development patterns that limit site disturbance, retain existing natural systems and minimise impervious surfaces.

A reduction in contaminant sources can be achieved through sediment and erosion controls, isolation of hazardous material sites, minimising the use of construction materials that leach contaminants, and appropriate applications of land management practices (e.g. fertilisers and pesticides).

E3.1 Minimising site disturbance

The Site Analysis phase discussed in the previous section directs development to the most appropriate areas of a site to minimise disturbance. This includes minimising the potential extent of bulk earthworks. For construction phases, documentation should set out a 'limit of work' line, and lock down staging and minimal access requirements. Minimising site disturbance should also be considered in the maintenance regimes of the operational phase of a development to ensure that WSD approaches and their requisite functions are protected.

E3.2 Reducing impervious surfaces

Reducing impervious surfaces will increase opportunities for rainfall to be attenuated within vegetation and soils. This will moderate stormwater volumes and reduce the capacity requirements for infrastructure and treatment practices in the catchment. Reduced imperviousness is also likely to reduce the contaminant load, since there is less surface area for deposition of contaminants and more vegetated areas to capture and transform contaminants. Reducing impervious surfaces may include the following approaches:

- Shared driveways
- Shared road surfaces for low traffic environments (as discussed in Section D5.3)
- Replacing impervious surfaces with pervious paving, living roofs, etc.
- Aggregating buildings and ancillary structures to reduce total footprint and access requirements
- Setting building configuration and heights to provide for optimal and flexible uses, including underground parking and mixed use development as appropriate
- Locating proposed developments close to existing access.

The redevelopment of a brownfield site allows an opportunity to re-evaluate impervious extents for current and future uses. Retrofitting catchments provides opportunities to extend the design capacity of existing stormwater management infrastructure or to reduce existing impacts on receiving environments.

Challenges and solutions

The table below describes some of the common issues relating to reduced impervious surfaces. In all circumstances there is a potential design solution, which must be balanced against other objectives for the project.

Challenge	Solution
Some land uses require a high level of imperviousness	In highly impervious areas such as civic and industrial sites, the key is to direct stormwater from reticulated systems to vegetated landscape areas or to WSD stormwater practices that utilise natural systems and processes (raingardens, living roofs, etc). Pervious paving should also be considered (refer Section E4.5).
Emergency service access requires specific road widths and turnarounds	Turnarounds can be avoided through a connected roading grid, accommodated by no-parking restrictions in specific areas, or replaced by 'T' turning points, or reinforced grass areas at road ends.
Parking is sometimes required for visitors, events, or future proofing for increased densities	Parking locations should be evaluated for their appropriateness to the site, taking into account the neighbourhood as a whole, potential for garaging under buildings, and associating future high density or commercial areas with public transport hubs. Where parking is deemed appropriate, potential strategies to reduce imperviousness include shared area for opening car doors, pervious area forward of wheel stops, and one way angled parking. Parking substrates, especially 'overflow' parking can utilise pervious pavement or reinforced grass materials. Refer to the Auckland Transport Code of Practice (ATCOP) for more information.
Roading responds to Council standards	ATCOP describes a broad function for roads to contribute to quality urban design. Appropriate carriage widths are an expected outcome of this design approach. Although councils have roading standards they do have flexibility to reduce road widths. The widths are assessed on a case-by-case basis, dependent on development form and potential effects to the environment (narrowing roads to protect significant features or limiting earthwork impacts to slopes). Alternative carriage widths are particularly appropriate for structure planning, where broader scale roading networks, street hierarchy and streetscape environments can be simultaneously addressed.
Urban design networks promote a connective urban grid	There is a balance between roading effects on the environment and ensuring connectivity and free flowing traffic within a community. A connected road grid can reduce arterial roads and their associated wide carriage widths and provide opportunities for more low traffic roads with enhanced landscapes.

Challenge	Solution
Footpaths are required for pedestrian-oriented communities	Footpaths can be eliminated in many instances through shared surfaces in community streets and laneways. Where dedicated footpaths are appropriate, consider using pervious materials or directing impervious surfaces to landscape areas or vegetated practices such as raingardens and swales.
Kerbs are perceived as neat edges for residential streets	Flexibility should be maintained around kerb edges, to utilise a combination of flush kerbs, broken kerbs, or directing kerbs to WSD practices. The Auckland Transport Code of Practice (ATCOP) requires kerbing for urban streets, however allowances are given to drain the road to stormwater control devices.
Driveway lengths are affected by conventional approaches to building setbacks	Back lanes can reduce the need for individual driveways (refer to 'WSD streets' in Section D5.3), otherwise the extent of driveways can be reduced by a single shared access to multiple garages or multiple lots. Setbacks can be reduced to bring houses close to roads. Other alternatives include providing wheel tracks rather than a single service, using pervious materials such as porous concrete or pavers, or directing stormwater runoff to raingardens or filterstrips on individual lots.
Gradual increases in imperviousness can result from subsequent land owners accumulating paths, sheds, etc.	Pre-empt the needs of future occupiers through site designs, or set expressed limits on ancillary structures, protection of green space and extent of earthworks.
Building and structure footprints	Consider living roofs and walls for structural surfaces (refer to Section E4.4 on living roofs that follows), or direct runoff from roofs to landscape areas or dedicated stormwater practices. Consider clustering buildings and ancillary structures to share access and foundations, or build upwards for infill situations.
Soils to be re-opened from under impervious surfaces may have limited infiltration capacity, especially where they have been earthworked	The restoration of topsoil and subsoils over relatively impermeable subsoil layers will still attenuate significant quantities of stormwater. Modified subsoils can also sometimes be rehabilitated.
Structural strength of the subbase may be affected by removing impervious surfaces and introducing groundwater flows	When removing impervious surface consider set back distances to structures, use additional drainage adjacent to structures, or investigate the use of pervious structural soils.

Melbourne, Australia

E4.0 At-source stormwater management

WSD promotes the management of stormwater runoff as close to source as possible. This provides for the retention and infiltration of stormwater throughout a catchment, and thereby reduces the potential for lower catchment stormwater effects.

There is a large suite of potential at-source responses discussed below, including soil rehabilitation, re-vegetation, capture and re-use of stormwater, living roofs and walls, and pervious paving. Devices such as infiltration and soakage trenches and gross pollution traps can also provide benefits when used close to source.

Note: Technical design guide documents provide detailed advice for design and construction of devices.

E4.1 Soil rehabilitation

There are a variety of methods for soil rehabilitation depending on machinery access, parent geology, topography, slope, aspect, and availability of soil additives. Auckland Regional Council Technical Report TR2009/083 *Landscape and Ecology Values within Stormwater Management* (Lewis et al., 2010) provides further guidance on soil rehabilitation practices, but some of the common approaches are discussed below.

Mechanical cultivation

Where larger earthmoving equipment has access, soil rehabilitation methods can involve deep tillage or chisel ploughing to break up deep soil layers to about 900 mm without mixing in surface soil layers. These methods disaggregate and aerate compacted soils. In other areas, such as around existing buildings or on small sites, it may be possible to do shallow soil remediation using tractor mounted or hand operated equipment such as a rotary hoe.

Allophanic and granular soils can be enhanced 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 to provide increased water percolation and root movement into subsoils.

Amendments and planting

Most soils in earthworks 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 material such as compost to promote plant growth, water uptake and water storage. Mycorrhizal fungi can also be incorporated (through inoculation by spray) into topsoil horizons to accelerate soil biodiversity and productivity.

Grass heights over 100 mm or dense tree planting increase soil macroporosity and permeability through root activity. Plants transpire, increasing water absorption capacity in the soil. This can be encouraged by planting in grids like orchards. Plants also add organic matter, which enhances the diversity of biological interactions in the soil.

Contaminated soils

It would be necessary to collect and analyse soil samples to ascertain whether any existing soil contamination issues are appropriate for intended land uses. Options to avoid excavation include capping contaminated soils with hydrophobic clays or re-surfacing with topsoil and compost to allow natural rehabilitation of soils.

Where there are low levels of contaminants, relative concentrations can be reduced through their dispersal throughout a site and phytoremediation processes, i.e. utilising plants to metabolise pollutants to innocuous forms or that are readily transported as coppice or leaf litter.

Bayside Reserve, Browns Bay, Auckland

E4.2 Terrestrial re-vegetation

Re-vegetation reduces stormwater runoff in catchments through the interception of rainfall in the canopy, infiltration through root systems, and transpiration. These re-vegetated areas can also function as filter strips to treat contaminants, slow overland flows, and attenuate stormwater quantities. There is a suite of environmental services provided by vegetation within a catchment, including enhancing biodiversity and ecosystem values, landscape amenity, dust interception, and temperature moderation.

Trees in particular have several advantages over other vegetation in improving water quality. They uptake nutrients, stabilise banks and steep slopes, transpire significant water volumes, and contribute carbon as fallen material that aids in denitrification processes in soils. Trees also provide a shaded environment that slows the establishment of weed species and reduces stormwater runoff temperatures.

The effectiveness of vegetation for stormwater quality treatment is dependent on the organic content and structural diversity of associated soils, and the relative proximity of root systems to groundwater. Fungi and microbes, abundant in healthy soils, aid in the translocation of nutrients to plants, and store other contaminants in inert forms. The organic layer of soil also intercepts and attenuates large volumes of stormwater, aiding in infiltration to subsoils. A mature forest can absorb up to 14 times the water of an equivalent grass area (Shaver, 2010a).

E4.3 Capture and re-use

Stormwater from rooftops can be captured for use in buildings and landscape areas, reducing the requirements for mains water supply. Runoff from ground level surfaces can also be captured, and often contain entrained nutrients which can be beneficial for irrigation of landscape areas.

Rainwater poses little health risk when applied to non-potable uses such as landscape irrigation or direction to toilets and laundry. Additional treatment such as redirection of first flush, cartridge filtration, or UV disinfection, is generally required when rainwater is to be used as a potable supply. In general, well-maintained rain storage facilities outside of heavily urbanised catchments are likely to only contain traces of nutrients and no contaminants in harmful concentrations. However, care should be taken for stormwater collection from treated timber, metals (copper and zinc), bitumen roofs, or beside air conditioning facilities. In all instances confirmation should be sought from the Council and health authorities prior to potable use of stormwater.

Rainwater from roofs can go to above or below ground storage facilities, but there is a preference for gravity fed situations or solar pumps to header tanks to reduce energy use. Raintanks come in many materials and finishes, with slim-line designs able to be placed partially underground or to fit underneath the eaves of buildings. Construction should also consider stress loading of a full tank and the necessity for maintenance access.

Collection of surface water flows from streets, yards, etc. usually requires pre-treatment prior to storage, usually in an underground facility. There are multiple systems on the market for underground stormwater collection, which balance the load bearing requirements of above ground uses with optimal water storage capacity. These systems may be applied to single lots or as combined systems to control peak flows and/or recharge groundwater in localised areas of permeable soils.

Harvesting and re-use of greywater and blackwater may also contribute to a holistic watercyle approach. However, this is not discussed as part of this guideline document.

Challenges and solutions

The table below describes some of the common issues relating to capture and re-use of stormwater. In all circumstances there is a potential planning or design solution, which must be balanced against other objectives for the project and the maintenance requirements of the approach.

Challenge	Solution
Raintanks are perceived as having high capital and life cycle costs	Raintanks may be the only feasible stormwater management response in a retrofit situation, where space is limited. Capture and re-use may also be justified by providing resilience to water supply. Raintanks are most appropriate if there are significant cost savings from diverting from watermain connections, and consequently reduced water rates. Communal systems for multiple units may provide for economies of scale, or underground storage systems can be investigated which usually have an increased service life and therefore a reduced life cycle cost.
Detention capacity may be reduced by multiple storms which also generally occur during low demand periods	Raintanks can be designed to have storage volumes for re-use, and a separate detention volume with a controlled discharge rate.
Superposition of peak flows may result from the combined overflow from raintanks in heavy or cumulative rainfall events	A controlled release point should generally be directed to vegetated landscape areas with enhanced infiltration capacity.
Purchasers of a property may not view raintanks as desirable, and instead view them as a liability	Raintanks should be designed for reduced maintenance and for multiple benefits, such as passive heating and cooling, and overflow to landscape irrigation. A manual describing raintank function and maintenance requirements and expected life of the device could be provided to the owners. Access to the tank should be provided for the ease of maintenance and/or replacement. Information on the benefits of raintanks to the owner and to the environment should be provided to educate the purchaser on the benefits of raintanks.
Tanks may be considered unsightly by potential purchasers	Water storage can be incorporated into architecture to integrate with or enhance the building design and structure. Water tanks can also be placed behind buildings or under decks with the use of a pump system.
Maintenance responsibilities	Raintanks require maintenance to ensure their long-term function. Raintanks should be checked every two years. Inspections should include: checking that pumps are still operational; checking if drainage connections to the tank are still functioning; and checking that connections to internal plumbing are operational, including backflow prevention valves. Any issues identified during the inspection should be the responsibility of the owner to fix.
Lifespan	Correctly maintained raintank systems have a design life of approximately 20 years. If maintenance is not performed, lifespan will reduce depending on whether pumps are used in the design and the potential for clogging of the tank inlets and outlets.

Rooftop in Atlanta, Georgia, USA

E4.4 Living roofs and living walls

Living roofs

Rooftops can represent approximately 40-50% of impervious surfaces in commercial and industrial areas and up to 25% for residential areas. Therefore, living roofs have a significant potential role to play in stormwater management (Dunnett & Clayden, 2007). Living roofs comprise a vegetation layer and growing medium over a waterproof membrane. They are aesthetically and environmentally rewarding for a wide range of commercial, residential and institutional applications. Further guidance for living roofs and walls can be found in Auckland Council Technical Report TR2013/045 *Living Roof Review and Design Recommendations for Stormwater Management*.

There are generally two understood types of living roofs: intensive and extensive. Intensive living roofs have a relatively deep soil media to support a wide range of plants and structures. These roofs often require additional load bearing structures. Intensive living roofs may be accessible spaces, providing gardens or parks above the street level. They can be also used to grow food if access is provided for residents.

Extensive living roofs have lightweight layers of free-draining media to support low-growing drought-resistant vegetation. Extensive living roofs have greater application to 'retrofit' existing buildings, as the additional weight loading is usually no more than 100 kg/m^2. Roofs with existing concrete tiles have merit, since they are designed to accommodate additional weight. Notwithstanding this, an assessment by a Council-recognised qualified structural engineer will need to be carried out to fulfil any building consent requirements.

Extensive living roofs are designed for maximum thermal and hydrological (reduced stormwater runoff) performance, and minimum weight load. This type of roof is not normally accessible, except for maintenance. However, they may be visually accessible from adjacent buildings.

The vegetation and media on living roofs capture atmospheric deposition of contaminants, promotes evapotranspiration, cools stormwater runoff, and slows down rainfall response times, thereby reducing peak flow rates and runoff volumes. Studies of extensive living roofs have indicated they can remove between 40% to 80% of annual precipitation through evaporation, depending on the climate and growing media (Carter & Rasmussen, 2006; Van Woert et al., 2005; Deutsch et al., 2005; Hutchinson et al., 2003, cited in Wises et al., 2010).

There are many benefits of installing living roofs in addition to stormwater management, including:

- Accessible or perceived open space
- Enhanced building design, or visually mitigating less desirable building aspects
- Reduced energy costs through insulation of a building and localised cooling around air conditioner intakes
- Noise insulation
- Enhanced air quality and dust interception
- Ambient temperature moderation
- Increased service life for underlying roof materials.

Living roofs can provide suitable habitat for tolerant or mobile animal and plant species. Within the urban centre of cities, living roofs may be the only 'green space' available, providing links or stepping stones in a network of habitats. Designing living 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).

Living walls

Living walls include plants growing directly on walls, on supporting structures, or within lightweight modular systems. Vegetation is similar to that specified for living roofs, with shallow root systems and resistance to drought (unless plants are climbing from an area at the base of the wall).

Similar to living roofs, living walls provide noise and heat insulation benefits. They may intercept direct stormwater precipitation or may have runoff from rooftops and like surfaces directed to them for irrigation. This will contribute to the reduction of peak flows and total volumes and may provide significant water quality renovation.

Challenges and solutions

The table below describes some of the common issues relating to living roofs and living walls. In all circumstances there is a potential design solution, which must be balanced against other objectives for the project.

Challenge	Solution
The cost of a living roof	Consider savings from reduced energy use, extended roof life, and the cost of an equivalent stormwater management response when undertaking life cycle costing.
The challenge to plant health in a fast-draining media	There are multiple pilot projects within Auckland and ongoing trials at the University of Auckland to determine the appropriate soil media to balance water and nutrient demands with the free-draining properties of living roofs. This information is provided in Auckland Regional Council Technical Report TR2010/018 *Extensive Green (Living) Roofs for Stormwater Mitigation: Performance Monitoring*. Many plants have also been trialled for Auckland conditions for a variety of elevations above street level, aspect, and media depth.
The weight of living roofs	Living roofs in Auckland have been formed with media as shallow as 70 mm thick with a high proportion of free-draining materials. 'Filter strips' of living roofs or larger plants may be applied over walls, beams, and columns.
The slope of roofs (>10 degrees for drainage) may not be suitable to retain media and plants	Soil retention methods may be adopted such as mounted boards, terraces and geotextile to reinforce planting media.
Construction access may be limited in retrofit situations	Plan ahead and allow time to obtain necessary permits. Plan roof construction work in parallel with other programmed construction activities. Utilise modular systems that are easily transported and in some instances pre-grown.
Performance in storm events	Living roof monitoring projects in Auckland have shown that living roofs meet WSD objectives for stormwater quantity control. This information is provided in Auckland Council Technical Report TR2010/018 *Extensive Green (Living) Roofs for Stormwater Mitigation: Performance Monitoring*.
Maintenance	Utilise safety barriers for access. Set in place irrigation systems and slow release fertilisers for plants to establish coverage quickly and to minimise ongoing maintenance requirements. Inspect the living roof to ensure it is still in place and that plants are healthy. Carry out any required maintenance identified during inspection.
Lifespan	Living roofs increase the lifespan of traditional roofs by a factor of two as they provide a buffer from harmful UV rays and thermal effects. Living roofs in Germany have been in place for 50+ years without the need for replacement.

Copenhagen, Denmark

E4.5 Pervious pavement

For the purposes of this guideline, pervious pavement refers to any system providing hard or trafficable areas which also provides for downward percolation of stormwater runoff. This includes the following systems:

- No-fines concrete or porous asphalt
- Permeable paver systems, where water percolates through gaps between pavers
- Porous pavers, where water percolates through the paver
- Stabilised loose material such as pebble or shell held in reinforced units or bound by resin.

There are also many products in the marketplace for reinforced turf that are appropriate for occasional traffic use. Many off-the-shelf products in the market provide their own specification, but the key functional requirements are the runoff percolation rate, required traffic loading rates, and the provision of washed aggregates of specific grades in the base course.

Pervious pavements can be designed as standalone water quantity treatment practices by providing below-ground storage for the water quality volume within base course layers. This reduces peak flows and total volumes (through some evapotranspiration), and improves water quality through filtration and sedimentation. Pervious pavement systems have shown excellent water quality enhancement for total suspended solids and metals. However, nutrients bypass these systems unless an anaerobic water storage layer is provided in the base course for denitrification processes to occcur.

A stabilised catchment before and after construction is essential to prevent premature clogging of pervious pavement. Post-construction movement of sediment from landscaped areas must also be avoided.

Pervious pavement can come in a variety of colours, shapes and textures and can often be useful to demarcate bus stops and pedestrian areas. Pervious paving can also be used for low trafficked areas including vehicle and equipment storage, and parking zones.

Challenges and solutions

The following table describes some of the common issues relating to pervious pavement. In all circumstances there is a potential design solution, which must be balanced against other objectives for the project.

Challenge	Solution
Auckland soils may limit potential for infiltration	Under-drains may be required to drain the base course above low permeability soils. A restricted outlet can provide storage and achieve the required residence time for stormwater.
Paver movement may occur on slopes and highly trafficked areas if not suitably constructed	Particular attention must be applied to turning areas, as well as road lengths where frequent accelerating and decelerating occurs. Pervious strips can be applied outside these areas to receive sheet flow from the balance of the site. A herring-bone pattern should be applied so that pavers lock together downhill. Pavers should be laid from the bottom of the slope upwards.
Compression strength of porous concrete may be less than normal concrete or asphalt	Porous concrete has been shown to have very high infiltration rates, and this is only partially reduced if smaller aggregates are required for higher compression strength. Super plasticisers can also improve final compression strength. Strips of porous concrete can be used in areas where there is unlikely to be turning by vehicles, thereby reducing potential effects to the concrete surface. Reduced compression strength is mitigated to an extent by an increased aggregate layer in the subbase.
Saturation of subsoils may affect the integrity of adjacent structures	Pervious pavement should be designed for the site conditions, with potential to include greater depths of drainage layers, impermeable liners, and geogrids to isolate stormwater from adjacent structures.
Sediment from an erosion event or spill may fill the voids of pervious pavers	Pervious pavers may be cleaned by mechanical brushing combined with vacuum trucks of a very specific power rating. Movement of fines to bedding layers may require replacement in some areas, but the base course is likely to remain unaffected. Stabilise the sub-catchment before pervious pavement is brought online. Porous pavers and concrete can be waterblasted. Oil and grease spills are very difficult to clean out and may require replacement of the surface, if it is a concern.
General loss and wash-out of aggregates may occur between pavers	Topping up may be required, but in heavily impacted areas, water based resins or permeable grout materials may be considered as an alternative.
Total costs are higher than standard hard surfaces due to increased base course and care required during instalment	The stormwater management function of pervious paving saves on the equivalent cost of an alternative practice and/or land area to accommodate it. Specialist products are becoming more commonplace and contractors are becoming more efficient in their installation, bringing costs down over the medium term.

Challenge	Solution
Maintenance requirements	Pervious pavement should be inspected every two years if other areas drain to the surface and every five years if the installation is standalone. Any issues identified during inspection should be rectified.
Lifespan	If maintenance is performed correctly and the right pavement is chosen for the site, pavement life should be similar to non-pervious surfaces. Surface designs adjust construction materials to ensure pavement servicability is equivalent to their non-pervious alternatives. For example, pervious concrete mixes can contain up to 30% more cement than traditional concrete to provide extra strength to offset the effect of removing fines from the mix.

E4.6 Infiltration and soakage trenches

Infiltration trenches receive runoff in a shallow excavated trench that has been backfilled with aggregate to form a below-grade reservoir. Water then enters the underlying subsoil according to the infiltration rate of the native soils. Infiltration is effectively a means to reduce stormwater quantity and peak flows, and to provide local recharge of groundwater.

Ideally pre-treatment would be provided prior to infiltration to prevent clogging of the device. Infiltration and soakage trenches are often encountered at the end of a treatment train, or where they receive relatively clean roof runoff with appropriate systems in place to divert the first flush of contaminants.

There may also be specific constraints for these practices where slope stability is potentially affected by groundwater (making geotechnical approval necessary) and localised mounding of groundwater, which may affect extractive bores, structural soils or foundations (requiring civil engineering assessment).

E4.7 Gross pollutant traps

Where catchment conditions are likely to contribute a large amount of litter or gravel in stormwater runoff, a gross pollutant trap (trash rack or debris screen) may be appropriate. Gross pollutant traps perform an important function at the inlet of bioretention practices and wetlands to reduce large contaminants (particles >5 mm) that may clog the system and reduce performance.

Gross pollutant traps provide ease of maintenance to capture large contaminants, but at the same time require a regular maintenance regime to clear these systems. Wet wells in particular should be cleaned so that materials do not decompose, increasing biological (biochemical) oxygen demand (BOD) and available nutrients. Gross pollutant traps have traditionally been constructed as cages, filters or wells, but there are opportunities to investigate 'natural' alternatives to these practices. For more information on the maintenance of gross pollutant traps, refer to the Auckland Regional Council Technical Report TR2010/053 *Operation and Maintenance of Stormwater Treatment Devices in the Auckland Region*.

Sydney, Australia

E5.0 Filtering and conveyance

Both filter strips and swales achieve treatment of stormwater runoff while conveying it through the catchment. Specific mechanisms include:

- Contact with soil to detain runoff
- Increased roughness to slow flow velocities and increase time of concentration
- Filtering medium to coarse grained sediments through plant and soil materials.

Note: Technical design guide documents provide detailed advice for design and construction of devices.

E5.1 Filter strips

Vegetated filter strips receive stormwater runoff as sheet flow from impervious areas. They are excellent for the treatment of stormwater runoff from small and frequent storms, effectively directing stormwater to landscape areas as passive irrigation.

Filter strips may include existing vegetation and may support a combination of herbaceous plants, shrubs or trees. Selection of vegetation is dependent on characteristics of the site and on stormwater runoff quantities and velocities. Water quality treatment performance will vary in accordance with the type and maturity of vegetation and the diversity and depth of soil layers.

Depending on the residence time, a filter strip may function as a sole stormwater treatment practice, or alternatively as a primary treatment practice capturing moderately coarse particles within a treatment train. Some portion of stormwater runoff may also infiltrate into the ground.

The key to the performance of filter strips is an even dispersal of flows across vegetated areas in order to optimise contact with soil and plants and to avoid concentrated flows (which may lead to the formation of rills and localised erosion). Filter strips may employ a level spreader, contour drain or exfiltration trench at the point of stormwater discharge to ensure an even dispersal of flows.

Critical elements for the function of filter strips include the length and steepness of the slope. Filter strips are generally less than 5% grade, unless terracing or level spreaders can be incorporated mid-slope. Grass filter strips should be mown relatively long (>100 mm high grass). Periodic inspection is also recommended for identification of non-biodegradable materials, erosion or clogging by heavy sediment.

As for other WSD practices, filter strips can be integrated into existing or proposed landscape elements. Typically filter strips are located along impervious surface boundaries such as carparks and roadways. The buffering function of these practices can be important for protecting the microclimate and interior habitat of remnant vegetation and streams. Filter strips can also provide a suite of environmental benefits for water and air quality, interception of dust, and cooling of ambient temperatures.

E5.2 Vegetated swales

Vegetated swales can be mown grass or any vegetation type that is stable under stormwater flows. These systems simultaneously convey and treat stormwater runoff. The typical location for swales is next to impervious surfaces such as parking areas and roads, with the potential to take the place of kerb-gutter-pipe systems.

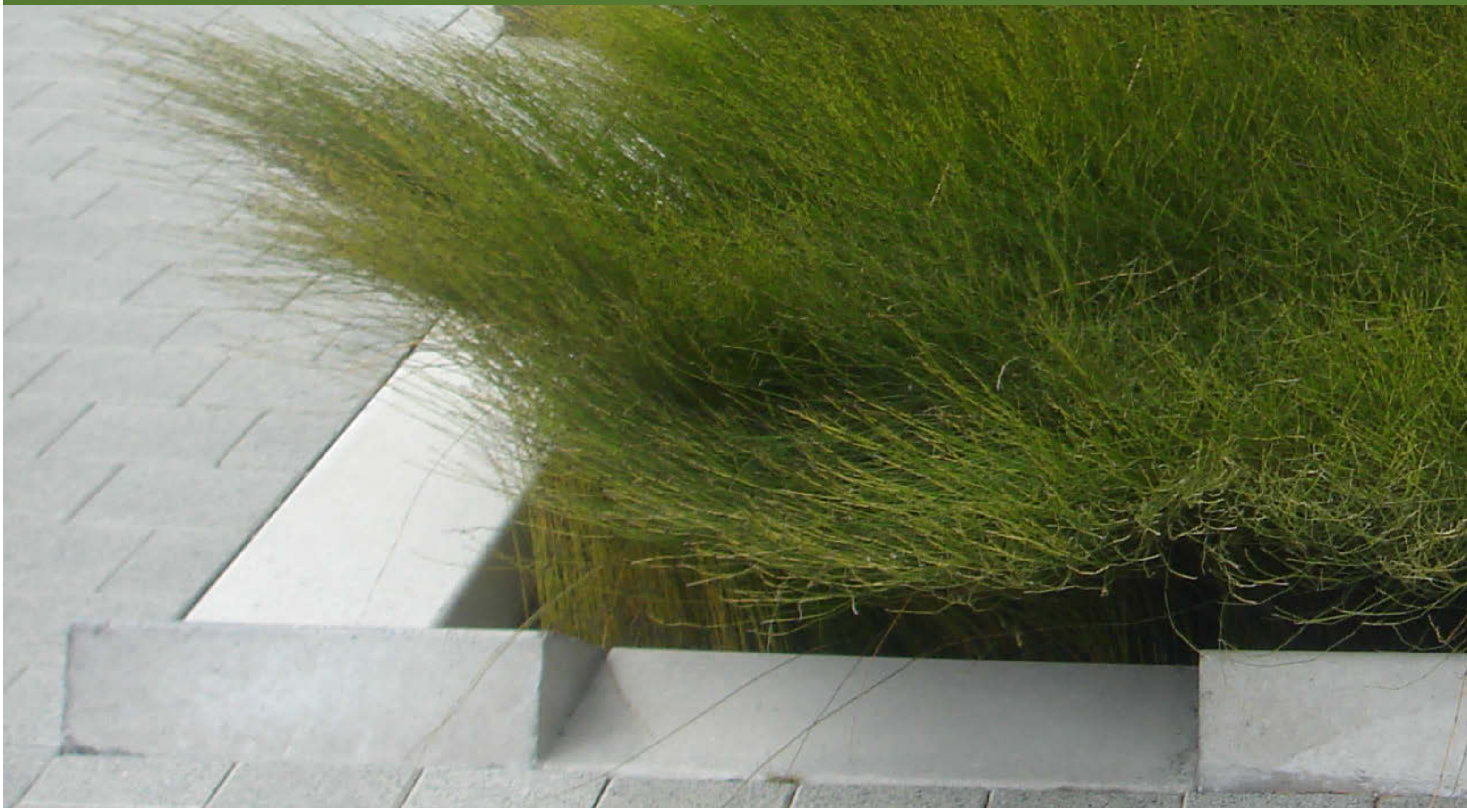
Their linear nature allows the filtering of sheet flows down channel side slopes and then conveyance and further treatment of contaminants along the base of the swale. Treatment is achieved by reduction in flow velocities across a vegetated surface, providing for filtering of contaminants and increased contact time at the plant-soil-water interface where treatment processes occur. The slowing of stormwater flows in vegetated swales increases the time of concentration for stormwater in the catchment and reduces peak flow. It also provides opportunities for infiltration to groundwater.

Dense vegetation and low velocities ensure reasonable treatment effectiveness in swales. Swales are effective at removing metals and coarse to medium-sized sediments. They may act as a standalone water treatment practice where there is sufficient residence time or may provide primary filtering within a treatment train. They may additionally act as level spreaders onto landscape areas for high flow events.

Swales can be integrated into existing landscape elements through alignment with natural flow paths and integration with planting schemes or natural plant communities. In flat areas, swales may be very wide to form subtle undulating flow paths. The linear nature of swales make them suitable for defining boundaries, separating pedestrians from traffic, forming a boundary to mitigate unwanted views, or forming intentional axes or dominant lines within a landscape. Swales also play an important role in softening the expanse of impervious infrastructure such as within car parks or road medians.

Swales are dynamic environments experiencing both rapid inundation and drought. However, they may represent and include relatively diverse plant communities, similar to those associated with intermittent streams and floodplains.

Sydney, Australia



Challenges and solutions

The table below describes some of the common issues and constraints relating to the implementation of filter strips and swales. In all circumstances, there is a potential design solution, which must be balanced against other objectives for the project.

Challenge	Solution
Slopes steeper than 5% are considered inappropriate for swales and filter strips	Swales can be used on steeper slopes (5-8%) utilising weir structures to provide for grade changes. Similarly, filter strips can use terracing or mid-slope level spreaders to reinforce slopes and evenly disperse flows.
Erosion may result from filter strips and swales being brought online before vegetation is established or from preferential flow paths	Use erosion control fabrics and check dams, or consider diversion around a swale while vegetation is establishing. To prevent erosion during operation, utilise check dams and densely plant in off-set rows. Maintain grass in swales at no less than 100 mm high to reinforce channel stability.
Infiltration potential may be undesirable due to groundwater levels and structural soils	Impermeable clay liners or underdrains may be utilised along the base of swales to prevent infiltration to adjacent structural soils or to high groundwater.
High sediment loads can create unsightly sedimentation within swales and at the edges of filter strips	Dense planting and/or a reduced mowing regime may localise sediment accumulation for later removal and prevent its transport to the base of the swale. A level spreader, in the form of a gravel trench, permeable dish or berm can capture sediment at the transition between the contributing catchment and swale/filter strip where it can be easily maintained.

Wellington City, New Zealand

Challenge	Solution
Insufficient space may be available to accommodate vegetated side slopes	A swale may be designed with steeper reinforced side slopes or with vertical walls, so long as entry points are reinforced and tripping hazards are addressed.
The length of a swale may not be long enough to provide for the designed residence time	Where a swale is a preferred option as a sole treatment practice, additional residence time can be achieved through a permeable base, check dams to detain stormwater volumes, and dense and taller vegetation to slow velocities.
The catchment may only allow defined entry points to swales	Level spreaders can direct flows across the side slopes of a swale to achieve full treatment potential. Where the side slopes are not required for treatment, there can be appropriately reinforced point discharges to the swale at regular intervals.
Continuous swales can prevent access	Pedestrian and vehicular access across swales can be constructed with boardwalks and permeable crossing structures to allow flows to continue through the swale.
Maintenance	Inspection should be carried out every two years. Any issues identified during inspection should be rectified.
Lifespan	Correctly maintained filtering and conveyance practices that utilise an underdrain have a design life of 50 years. If no underdrain is used, design life can exceed 100 years. Lack of maintenance can cause blockage and scour, which may require the replacement of the asset to restore function.

Papamoa, Tauranga

E6.0 Bioretention

The most common bioretention practices are raingardens, tree pits and planter boxes. These systems are discrete landscape areas that use specific soils and plant materials to manage stormwater effects. Tree pits are essentially raingardens with a single tree rather than smaller foliage plants. Planter boxes are usually lined bioretention areas which receive point source runoff from rooftops or adjacent hard surfaces. The stormwater management functions provided by bioretention practices include:

- Filtation of stormwater through surface vegetation
- Settlement of sediments by surface ponding
- Dentention of stormwater volumes in soil media and surface ponding
- Filtration of contaminants through soil media
- Microbial treatment processes in contact with soil and root horizons
- Infiltration to ground and evapotranspiration.

Bioretention practices are usually a secondary treatment practice, meaning the inclusion of a filter strip or gross pollutant trap for pre-treatment will make them less vulnerable to sediment loading. This requires specific maintenance regimes during operational phases, and protection measures from sediment loads during construction phases. For more information on maintenance, refer to Auckland Regional Council Technical Report TR2010/053 *Operation and Maintenance of Stormwater Treatment Devices in the Auckland Region*.

Bioretention practices can be integrated seamlessly into existing landscapes or proposed planting schemes. The ecological value of bioretention practices is limited by climatic effects and isolation within the catchment. However, these practices may still provide a refuge for urban wildlife and a means to promote native species dispersion into the urban environment. This is particularly true of bird species. There are a number of opportunities to maximise ecology values for bioretention practices, including:

- Using diverse native plant species to provide food for birds and insects all year round
- Applying multiple tiers of planting, from ground cover species to canopy and emergent trees, providing a range of habitat niches of cover and food. Multi-tiered planting can also form microclimates to accommodate species that are sensitive to climatic extremes.
- Including threatened plant species if conditions are appropriate and if there is a means to support their ongoing population and dispersal
- Incorporating rocks or driftwood to provide habitat for lizards and skinks. Rotting logs, twigs and leaves provide habitat for both insects and lizards.
- Utilising the potential to form a transitional edge to existing vegetation. In such cases it is also important to consider the existing hydrology of adjacent vegetation and ensure this is not impacted by rainwater collection in the practice.

Note: Technical design guide documents provide detailed advice for design and construction of devices.

E6.1 Raingardens

Purpose-built raingardens have been used successfully overseas and in New Zealand for over 15 years. Stormwater runoff enters a raingarden through vegetation layers at the surface, before it soaks into soil media. More information on soil media can be found in the Auckland Council Technical Report TR2013/011 *Media Specification for Stormwater Bioretention Devices*. Depending o0.n underlying subsoils, stormwater may then infiltrate to groundwater or be collected and piped to a discharge point. Ponding on the surface of the raingarden is called 'live storage' and is designed to dissipate over a period of 24 hours as a function of media permeability and evapotranspiration rates.

In many locations where conventional landscape areas would occur, raingardens can be used instead. This includes roadside verges, traffic islands, parking areas and around existing catchpits. Landscape design is an important consideration for the construction of raingardens, since attractive features encourage landowners to take pride and stewardship over the maintenance of these facilities. Maintenance plans should be provided to the landowner to promote the use of correct maintenance procedures. Specific responses to landscape are discussed in Auckland Regional Council Technical Report TR2009/083 *Landscape and Ecology Values within Stormwater Management* (Lewis et al., 2010) including:

- Incorporating raingardens into the existing landform
- Reinforcing existing or visible landscape patterns
- Enhancing urban ecology and natural character values
- Contributing to streetscape amenity and providing a visual cue for traffic calming
- Integrating, framing or complementing architectural forms and landscape spaces.

Wynyard Quarter, Auckland

Sydney, Australia

E6.2 Tree pits

Tree pits require a sufficient quantity of soil media to support trees through maturity. Trees can intercept additional rainfall in their canopy, direct rainfall to tree pits via stemflow, and percolate stormwater runoff through soil layers and root pores.

Tree pits often have bypass systems to avoid localised ponding from surface runoff. Tree pits may also require increased drainage such as perforated coiled pipes to avoid continuous saturation of root zones and to aerate soils. These pipes can also be used for watering the trees during dry periods by adding water through the cleanout. Where the area around the tree roots is likely to be trafficked, additional structural support may be required, such as a concrete wall, structural soils or specialised root cells.

A research paper by the University of Melbourne outlined the relationship between stormwater treatment and horticultural requirements for street trees (Kerrie et al., 2008). Results indicated that stormwater provided for faster growth rates than tap water, possibly due to increased nutrients. The study also showed that it is feasible to use under-pavement tree pits as a stormwater treatment method and that tree growth was satisfactory in soils with a range of infiltration characteristics. Even at a very young age, trees appeared to modify the hydraulic conductivity of tree pit systems.

Trees are important green infrastructure in urban environments, providing oxygen, passive cooling and heating, intercepting dust, and acting as an ecological corridor for avifauna, lizards and insects. Trees are also an important landscape element, providing seasonal interest, defining landscape corridors, and establishing human-scale spaces under their canopy.

E6.3 Planter boxes

Planter boxes are similar to raingardens, but are usually in an encapsulated environment that receives a point source of stormwater runoff, such as roof downpipes. Stormwater planter boxes may be included in any location where conventional planter boxes are used, including building facades, courtyard spaces or rooftops.

The nature of these systems allows them to be elevated above the ground, acting as edges to spaces, or seating walls. Where these systems are integrated with architecture there may be requirements for an impervious liner or increased structural loading.

Challenges and solutions

The table below describes some of the common issues and constraints relating to the implementation of bioretention practices. In all circumstances, there is a potential design solution, which must be balanced against other objectives for the project.

Challenge	Solution
Standing water may be unsightly, have smells, and be a vector for insects	Surface ponding is designed to drain over a 24 hour period to prevent stagnation. Average ponding depths are 200-300 mm which can be screened by vegetation and/or rocks.
Rubbish and sediment can build up in practices and affect performance	Inlet systems and overflow structures can be designed to trap and separate floatables and sediments. Erosion within the device should also be prevented through energy dissipators at inlets. Regardless of these approaches, bioretention systems will require periodic maintenance to ensure the best operation.
Residency time for detention of stormwater volumes must be balanced with loading rates for water quality treatment	Residency time can be controlled through a restricted outlet or an adjustable level control.
Maintenance requirements are seen as being greater for bioretention practices than for catchpits	Bioretention practices provide a very effective return on investment for water quality treatment and volume reduction, including relative maintenance costs. Apart from general litter removal, which is applicable to most landscape areas, bioretention practices are generally designed to self maintain. The application of mulch is the key requirement until plants establish. Periodic monitoring of bioretention practices during storm events will identify potential operation or clogging issues.
Groundwater levels may be affected by bioretention, which may affect stability of adjacent slopes and structures	Increase drainage rates and/or line the bioretention practice to prevent saturation of adjacent soils. In some cases, bioretention practices may not be suitable for use near steep slopes.
Space is not available for bioretention practices	Bioretention can be retrofitted and can be any shape to fit within spatial constraints. Planter boxes may be used inside foyers of buildings, or may be cantilevered on the outside of buildings. Tree pits can occur in footpaths, roadways or courtyards. Their encapsulated forms allow cantilevering structures above them, which can be paved and may be designed to sustain the weight of people and vehicles.
Conflicts with existing infrastructure	Infrastructure can be protected behind root guards or concrete gaskets. Additionally, tree roots can be confined and guided to specific locations through root 'cell' technology.

Challenge	Solution
Slope constraints	The use of retaining structures, check dams and terracing may address slope issues. Planter boxes can be stepped down a slope, with the drainage pipe from a previous planter box entering the upper soil horizons of the downhill planter.
On-site soils may be unsuitable for use in the raingarden media	In general, Waitemata Group clay soils are not suitable for use in raingarden media. There are manufactured commercial mixes of bioretention media available, or a custom media may be developed as described in Auckland Council Technical Report TR2013/011 *Media Specification for Stormwater Bioretention Devices*.
Plant health may be affected by contaminants in stormwater	This can be addressed by species selection and appropriate soil media. In many circumstances tree growth rates will benefit from the increased nutrients associated with stormwater runoff. Contaminants will often be stored in organelles within plant cells, so effects on a plant's biological health are limited. In many instances, microbial processes within the root zone will transform pollutants into innocuous forms.
Safety issues for bioretention practices	There are specific examples where raised and sunken tree pits in New Zealand have led to serious public safety issues due to tripping and falls. Bioretention design should incorporate visual cues to their presence, appropriate tree guards, cantilevered or continuous pavers that prevent tripping, or seating walls or similar to prevent conflicts. Bioretention in roadways should consider pedestrian crossing points and opportunities for cyclists to leave the road to avoid erratic drivers.
Maintenance	Bioretention systems should be inspected every two years. Any issues identified during inspection should be addressed.
Lifespan	Correctly maintained bioretention systems have a design life of 25 years. If maintenance is not carried out, system life can reduce due to blockage and clogging. However, lack of maintenance does not ensure device failure.

Clearwater Golf Resort, Christchurch

E7.0 Detention and attenuation

Detention involves the capture, attenuation and controlled release of stormwater volumes before they discharge to receiving environments. This moderates peak flows, reduces runoff velocities allowing contaminants to settle, and increases contact time between vegetation, soil and water. There are limitations to relying on detention as a singular practice in the catchment, including the loss of land, and the potential for super-position of peak flows (refer to the water quantity objectives in Section B).

Note: Technical design guide documents provide detailed advice for design and construction of devices.

E7.1 Above-ground detention

Multiple areas of open space can detain a large cumulative quantity of stormwater runoff across a catchment. Existing ecosystems such as gullies and floodplains can also provide natural detention areas. Detention functions can be enhanced through minor grading or construction of a berm or wall to provide temporary ponding. Dam regulations should be considered to ensure all appropriate regulations are complied with.

Property owners and the wider community must understand that ponding is intended to occur in the area and should be made aware of the extent and frequency of flooding of a ponding area. Because of the multipurpose nature of areas being used, safety is an important consideration and the period of inundation should be less than 24 hours depending on access requirements.

In terms of hydrological function, above-ground detention (AGD) should have a controlled discharge outlet and an overland flow or large capacity pipe for larger storm events. These overflows also provide a safety valve, should an outlet from an AGD become blocked. Plants within ponding areas can provide some water quality benefit but must have tolerance to both temporary inundation and extended dry periods.

Westergasfabriek Park, Amsterdam, Holland

Challenges and solutions

The table below describes some of the common issues and constraints relating to AGD. In all circumstances, there is a potential design solution, which must be balanced against other objectives for the project.

Challenge	Solution
Standing water may be unsightly, have smells, and be a vector for insects	AGD are temporary storage practices, where surface ponding is designed to occur for a maximum 24 hour period between storms to prevent any stagnation. Any ponded water can be screened by vegetation and/or rocks. AGD on hard surfaces should be regularly maintained by sweepers to prevent 'sediment rings' from occurring.
Access may be restricted by AGD	Consult with stakeholders to manage expectations for public facilities. Alternative access options should be provided for any areas that will be inundated. Structures or facilities should remain above ponding areas to prevent water damage and allow continual use.
Velocities and water depth may cause a hazard	Where overland flow paths are accessible to the public (roads and pedestrian routes), ensure that there is adequate signage to warn the public of the potential hazard.
Flooding may extend to other properties	Make sure there is sufficient freeboard (see PAUP rules) to buildings in the 100 year ARI event floodplain and allow for a dedicated overland flow path.

E7.2 Wetlands

Wetlands are complex natural systems of hydric soils and water-loving plants. Natural wetlands provide many important functions, including the attenuation of flood flows, water quality treatment, and support of aquatic plants and wildlife. Stormwater wetlands mimic the treatment processes of natural wetlands for detention, fine filtration and biological adsorption, to remove contaminants from stormwater runoff. Further guidance for wetland systems can be found in Auckland Regional Council Technical Publication TP10 *Stormwater Management Devices: Design Guidelines Manual* (2003).

Stormwater wetlands generally consist of an inlet zone (sedimentation basin or forebay), a planted zone, and a high flow bypass channel. The planted zone generally caters for the water quality volume and the detention of post-development peak flows. Wetlands can also be used for higher detention requirements. There are three main types of constructed wetlands:

1. **A surface-flow (SF) wetland, including wet swales**
   Water flows across alternating zones of deep water pools and shelves of wetland plants to perform different stormwater treatment functions.

2. **A subsurface flow (SSF) wetland**
   Stormwater 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 sediment concentrations to prevent clogging, and relatively uniform flow conditions to ensure plant survival (Davis, 1995).

3. **A floating treatment wetland (FTW)**
   A FTW is a raft that supports wetland plants, growing in a hydroponic manner within a water basin (Headley & Tanner, 2006). FTWs are still a relatively unproven technology in stormwater ponds but laboratory and mesocosm trials have revealed there is significant potential for these systems to filter 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. They can be retrofitted to existing ponds.

Michaels Avenue Reserve, Ellerslie, Auckland

Treatment wetlands are effective at treating suspended solids, hydrocarbons and dissolved metals. Nutrients such as nitrogen and phosphorus may also be taken up by wetland plants, given sufficient residency time.

Auckland Regional Council Technical Report TR2009/083 *Landscape and Ecology Values within Stormwater Management* (Lewis et al., 2010) provides specific guidance on enhancing landscape and ecology values within wetlands. If sited within accessible open space, constructed wetlands or ponds can significantly enhance the built environment. Wetland environments provide an urban refuge and a place of tranquility. Plants can form open sedgelands, dense flaxlands and cool and dark forests, providing for diverse and changing experiences for paths and boardwalks within a wetland.

Constructed wetlands are useful areas for outdoor classrooms, as they can demonstrate basic principles of plant succession, food webs and nutrient cycling. Biodiversity is optimised in a wetland through environmental gradients from aquatic to terrestrial zones, and from edge to interior habitats. A constructed wetland can attract a variety of wildlife by incorporating diversity of water depths, landform, substrates and plant communities. Wetlands 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.

Wetlands with connections to existing riparian environments offer excellent opportunities to provide fish passage for increased habitat offline (upstream of the receiving environment), and this is critical where wetland ponds are online (constructed in-stream). Refer to Auckland Regional Council Technical Publication TP131 *Fish Passage Guidelines for the Auckland Region* (Boubee et al., 2000) and Technical Report TR2009/084 *Fish Passage in the Auckland Region – a Synthesis of Current Research* (Stevenson et al., 2009) for ARC's fish passage guidelines.

Challenges and solutions

The following table describes some of the common issues and constraints relating to stormwater wetlands. In all circumstances, there is a potential design solution, which must be balanced against other objectives for the project.

Challenge	Solution
Standing water may result in increased frequency of mosquitoes, and stagnant water	Design wetland edges and flows to avoid short circulating. Combinations of shallow and deep areas provide opportunities for mosquito predators such as dragonflies and wading birds.
Safety around open water areas is cause for concern	Safety is paramount around open water. Access to these areas can be restricted through dense planting around margins. Safety shelves and shallow slopes allow egress from the water, should anyone find their way in.
Weeds in wetlands can lead to significant maintenance issues	Management of pests is outlined in Auckland Regional Council Technical Report TR2009/083 (Lewis et al., 2010). Stormwater wetlands should only occur where there is effective access and a regular maintenance regime. This allows weeds to be controlled when they are manageable. Weeds can also be prevented through dense planting, checking the quality of nursery stock to prevent transplants, varying water levels in the wetland, and controlling weed sources upstream.
Maintenance of wetlands can be significant, especially for the control of sediments	Wetlands are relatively self-maintaining once established, with only periodic checks required for inlet and outlet structures. Forebays are able to capture gross pollutants and coarse sediments and regular maintenance of these systems will extend the design life of wetlands. In other words, an increased rate of preventative maintenance will decrease the occurrence of more costly restorative maintenance.
Waterfowl may be attracted to open water areas and create water quality issues	Large numbers of birds can result in increased faecal material in and around the wetland or pond. Potential solutions include dense planting or rocks at the margins to reduce loafing areas, and planting tall vegetation to limit ‘flight lines’.
Lifespan	Correctly maintained wetlands have a design life exceeding 100 years. If maintenance is not carried out, sedimentation and scour can significantly reduce lifespan.

Pegasus Town, Canterbury

E8.0 Enhancing the receiving environment

In some instances the enhancement of the receiving environment may be preferable to upper catchment stormwater management responses. For example, in lowland environments, the enhancement of large wetland systems can restore the natural heritage of an area and create extensive and buffered riparian habitat. In all instances the receiving environment can be restored for greater resilience and to enhance the broader environmental framework of the site.

E8.1 Riparian buffers

In general, the extent and quality of stream vegetation has been shown to have a significant effect upon the water quality in the receiving environment (Becker et al., 2001; ARC, 2004; Rutherford et al., 1999; Allibone et al., 2001). Riparian buffers act as biological filters between catchments and receiving environments, intercepting a significant proportion of groundwater nutrients. Stormwater runoff is slowed and filtered, with direct uptake and transformation of contaminants by plants. Vegetation and humus layers attenuate significant volumes of water, promoting infiltration into the soil and releasing it over a longer time period to contribute to stream base flows and to support riparian vegetation.

Buffer widths

The 'edge effects' of sun, wind and pest invasion can extend over 40 m into mature vegetation (Davies-Colley et al., 2000; Young & Mitchell, 1994). A 10 m width planted on each stream bank is the minimum recommended by Auckland Council (Becker et al., 2001). Wider strips of 20 m or more are encouraged, particularly for larger rivers (Parkyn et al., 2000).

While the benefits associated with re-vegetating stream-side margins are well documented, the literature is inconclusive in terms of the necessary width of riparian buffer zones. However, it seems that the greater the width the more obvious the benefits to stream health. Parkyn et al. (2000) made the following observations about three selected riparian widths:

- **5-6 m**: Ongoing maintenance is required to keep a buffer of this width free of weeds, and the natural regeneration of indigenous species is limited. This width should only be used on very small watercourses or where there is no other option.
- **10 m**: Indigenous vegetation succession is allowed for, and relatively low maintenance is required. The outer edge (i.e. the edge furthest from the stream) is likely to suffer from long-term weed infestations, which could have the potential to spread to the interior wherever canopy gaps occur. This width should be used as a general guideline for a minimum buffer width.
- **20+ m**: It is highly likely that a buffer strip of this width would support self-sustaining indigenous vegetation with few maintenance requirements and is recommended to provide long-term benefits to aquatic and terrestrial biota.

In terms of aquatic habitat, buffers less than 10 m in width do not necessarily protect algal, macro-invertebrate or fish biomass and diversity. However, buffers wider than 30 m have provided observable protection (Davies & Nelson, 1994). Invertebrate communities in particular are strongly linked to temperature, suggesting that canopy closure and protection of headwaters is required for in-stream diversity (Parkyn, 2004).

There is a direct correlation between buffer width and contaminant removal rates. Nitrate removal of 100% has been recorded in buffers between 20 m and 30 m in width, and removal rates of over 70% where the buffers were 10 m wide (Fennessy & Cronk, 1997). However, the effectiveness of these buffers is greatly influenced by site-specific factors such as slope, soil composition and drainage patterns.

Collier et al. (1995) provide practical guidelines to calculate the optimal filter strip width in agricultural systems based on a CREAMS model (Chemical, Runoff and Erosion from Agricultural Management Systems). This model suggests a wider buffer zone is required for a greater slope length and angle, a larger clay fraction in the soil, and a lower soil drainage capacity.

Riparian planting design

The Auckland Regional Council Technical Publication TP148 *Riparian Management Guideline* (Becker et al., 2001) provides a step-by-step process for riparian planting. This includes a planting guide for a range of stream environments. In some instances, buffers comprising sedges and grasses can be very effective at stormwater management due to the following (MfE, 2001):

- They typically form a dense cover over the ground which slows down the passage of water. The effect of slowing down runoff on the floodplain needs to be considered when choosing locations for riparian planting.
- Their many fine leaves are ideal filters, reducing the velocity of water and encouraging the settling of solids.
- They grow well in saturated soils and can tolerate periods of immersion.
- They can tolerate and grow through accumulated sediment.
- They can be tolerant of dry periods.
- They are generally tolerant of both low and high fertility.
- They tend to accumulate organic matter and help create anaerobic conditions, which are important steps in lowering nitrogen levels.

Trees and shrubs are less able to intercept and filter out contaminants in overland flows since they do not have dense foliage at ground level. However, there is some evidence that thick layers of forest floor organic matter (humus) can be very effective as a contaminant filter. Forest buffers provide for greater nitrate removal from groundwater flows, partly through uptake by plants (Martin et al., 1999). Collier et al. (1995) also observed that a single line of trees can provide 80% shade to streams once they have achieved canopy closure.

Parkyn (2004) noted that due to the different contaminant forms and entry points for stormwater, a combination of grass/sedge/rushes and tree/shrub buffer types provides the most effective outcome. Shade-tolerant reeds, rushes and sedges could also be considered.

Kanazawa Kenrokuen Garden, Japan

In rural areas, there are a number of buffer zone management options that work alongside agricultural practices. Literature on the subject suggests unmown grass buffer strips are effective at filtering sediment and associated contaminants from surface runoff (Martin et al., 1999). Grass filter strips can be grazed on a rotational basis during dry periods to provide new growth and to uptake nutrients such as phosphorus. It may be possible to separate these grass filter strips from other pasture using electric wires to exclude cattle but allow sheep access. Combination buffers can provide an upslope grass buffer with appropriately spaced trees as a wood lot, with an undisturbed buffer zone next to the stream.

The Ministry for the Environment (MfE, 2001) provides specific recommendations for the harvest of productive tree species along riparian areas and dictates the most appropriate location, timing, techniques and extent of harvesting practices.

Habitat enhancement

The diversity of stream environments is a function of their hydrology, geology and climatic conditions. Habitats vary along gradients from upland to lowland environments and from floodplains to the base of the stream (groundwater zone). Enhancing riparian buffers provides excellent opportunities to improve both aquatic and terrestrial ecology including the following:

- Shade from riparian vegetation regulates water temperatures and improves dissolved oxygen levels in streams, allowing more sensitive species to thrive. Shade also reduces light levels to prevent nuisance growth of algae.
- Trees and shrubs provide inputs of leaves, wood, and insects as sources of food for fish and aquatic invertebrates.
- Woody debris provides in-stream heterogeneity, habitat diversity and cover. Bullies spawn on logs on the stream bed.
- Tree roots provide bank stabilisation benefits, as well as opportunities for overhanging banks and fish refuge.
- Low vegetation, such as sedges, grasses and rushes, provide spawning opportunities for galaxiids that lay their eggs at the base of these plants at the water's edge.
- Riparian vegetation provides habitat for terrestrial species such as birds, lizards and insects. Sheltered conditions afforded by trees and shrubs are necessary to support the terrestrial adult (reproductive) phase of many aquatic insects.

Forested stream profile

One factor that needs to be kept in mind for restored riparian buffers is the likelihood that the stream channel will widen due to an increase in shading and subsequent loss of grasses along the stream bank. Parkyn et al. (2001) suggest that bank erosion would peak about 25 years after planting, with sediment yields being approximately double the amount expected under herbaceous/grass ground cover. Following this, bank erosion and sediment yield would be expected to decline, reaching low levels when the stream has widened to its natural forest morphology by about 35-40 years after riparian planting.

To prevent additional sediment entering stream environments it may be necessary to re-profile streams based on post-development forested morphology. Erosion may also be prevented through maintaining a balance of shade trees and low-growing littoral vegetation or by utilising shade-tolerant understorey species.

E8.2 Protecting and enhancing wetland environments

Wetlands are permanently or intermittently wet areas and land-water margins that support a natural ecosystem of plants and animals that are adapted to wet conditions (RMA, 1991, s2.1).

Wetlands provide significant detention of stormwater and very efficient removal of nutrients, hydrocarbons, metals and sediment. Engineered treatment wetlands in Auckland are normally associated with a larger catchment size. However, multiple smaller wetlands are also an option where spring seepages or seasonal high water tables can support wetland vegetation.

One of WSD's principles relates to the treatment of stormwater as close to source as possible. However, where there are large floodplain areas which have low functional values and are unsuitable for development, there may be value in rehabilitating wetlands in these environments for engineered stormwater detention and treatment. This circumstance assumes treatment of gross contaminants prior to stormwater entering wetland environments.

E8.3 Protecting and enhancing coastal environments

Due to the sensitivity and values of estuaries and coastal margins, it is important to provide coastal environments with a resilient buffer to the effects of stormwater runoff. Upper catchment WSD responses reduce combined sewer overflows, mitigate lower catchment flooding, and capture contaminants prior to entry into marine environments. In particular, sediments should be captured before entrained contaminants such as heavy metals accumulate in marine sediments and bio-accumulate in benthic fauna (ARC, 2004).

Point source stormwater management is important for coastal and marine environments, including buffering land use activities, managing coastal outfalls to prevent erosion, and ensuring a level of water quality treatment appropriate for the sensitivity and values of the coastal receiving environment.

E8.4 Stream daylighting

Stream daylighting brings piped stormwater flows or buried streams to the surface and into restored stream environments. International best practice examples of stream daylighting have demonstrated significant economic returns and social benefits. Waterfront property commands a premium and can be a driving factor in urban revitalisation. Furthermore, citizens quickly engage with the restoration of natural heritage in their neighbourhoods, and become strong proponents for these approaches (Lewis, 2008).

Stream daylighting returns the ecosystem services of attenuation and treatment of stormwater runoff associated with open and naturalised streams, providing increased hydraulic capacity for flood management, and reduced runoff velocities. Stream channels are comparable in cost to piped systems in the short-term and more accessible for maintenance in the long-term. Like other existing ecosystems, these systems must be protected from gross contaminants and significant sediment loads from the catchment.

La Rosa Reserve, Green Bay, Auckland

E8.5 Parallel and in-stream wetlands

Urban streams are likely to face hydrological extremes (increased flow volumes during events and lower baseflow), stress on vegetation growth from adjacent land uses, and increased sediment and pollution loads. If stream restoration projects fail, they may cause flooding and bank collapse, which consequently leads to sedimentation of downstream environments.

Urban stream restoration must therefore focus upon 'rehabilitation' as opposed to 'restoration', to ensure the sustainable recovery of stream processes in a form that responds to urban catchment conditions. This may not require hard structural measures, but may necessitate design consideration for stream profile, floodplains, and innovative methods to stabilise banks.

If stream corridors are part of a stormwater management response, they require protection and maintenance. The integration of stormwater management within a stream corridor might include:

- Treatment practices running in parallel with stream corridors such as filter strips, wetlands or infiltration trenches
- A widened buffer, back wetland, or alternative flow path to accommodate combined sewer overflows
- Allowing stormwater wetlands to be inundated by spring tide conditions to augment inanga spawning habitat
- Floodplain habitats.

WSD represents a significant opportunity to rehabilitate natural systems and processes in association with receiving environments. These systems can be an important contributor to regional biodiversity and for passage of fauna from coastal to upland environments.

E9.0 Construction through operation phases

E9.1 Construction methodology

WSD promotes the protection of ecosystem resources, including existing vegetation and vulnerable soils. The construction phase of development requires best practice methodologies to ensure this outcome.

Implementing a detailed site survey (including a topo survey with mark-out) will allow a limit of work around areas to be protected and allow set out of access points and staging areas. This reduces the area of the site that is left 'open' and directs specific areas for construction traffic. In general, the lightest equipment and the fewest passes necessary should be applied to achieve site works.

Construction practices should also protect rootzones around trees, establish wind protection around remnant vegetation, protect groundwater interface for wetland areas, and retain 'clean water' surface runoff onto existing vegetation, where appropriate. Sediment and erosion controls should follow best practice guidance in accordance with Auckland Regional Council Technical Publication TP90 *Erosion and Sediment Control Guidelines for Land Disturbing Activities in the Auckland Region* (1999).

To ensure appropriate environmental management of a construction site, it is imperative to have representation from the project design team at pre-determined control points of the construction phase. Contractors undertaking developments with WSD approaches should be experienced and/or show a clear understanding through a detailed construction methodology and programme. The construction methodology and programme submitted in the tender phase should be given a high weighting, in reference to expectations for best practice.

E9.2 Bioengineering

Bioengineering uses natural construction materials to stabilise slopes and overland flowpaths. The approach starts with slope profiles that emulate a natural morphology, applies biodegradable materials for short-term protection, and utilises planting to achieve long-term regenerative slope stabilisation. Bioengineering approaches are flexible enough to allow natural systems to find their own equilibrium over time, and as environments change.

Lucas Creek, Albany, Auckland

Malmo, Sweden

E9.3 Operational phase

During the operational phase of development, there may still be high sediment loads from unexpected erosion in the catchment or from modifications to individual sites. An increase in fine sediment loads can cause critical failure in pervious paving or bioretention practices and should be controlled. Possible approaches to minimising sediment and contaminants entering stormwater runoff during the operational phase, thereby increasing the lifespan of stormwater management devices, include:

- Education of homeowners and local contractors on the function of WSD stormwater management strategies and practices
- Erosion and sediment control plans (ESCP) for individual sites appended to ownership deeds
- Temporary 'capping' of stormwater practices with a sand layer, rolled turf or geotextile, and ideally a combination of these, to protect practices from localised earthworks in the contributing catchment
- Filter strips to remove coarse sediments in stormwater prior to entering bioretention practices and to additionally protect these practices from accidental contaminant spills
- Landscape maintenance that reduces fertiliser and pesticide use
- Encouraging the use of inert materials in building construction and isolate treated timber and galvanised materials from stormwater runoff
- Provision of control pads for specific treatment systems
- Training contractors to maintain WSD approaches
- Access to private lots for maintenance of public stormwater management practices
- Provision of integrated maintenance contracts for roading, open space and stormwater practices including maintenance priorities and specifications
- Regular road sweeping, catchpit clearance and litter removal from swales and bioretention
- Following storm events, checking WSD devices for performance and operation relative to design intent.

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F2.0 Abbreviations

AC	Auckland Council
AGD	Above-ground detention
ARC	Former Auckland Regional Council
ARI	Average recurrence interval
AT	Auckland Transport
ATCOP	Auckland Transport Code of Practice
BOD	Biological (biochemical) oxygen demand
BPO	Best practicable option
CDP	Comprehensive development plan
CMP	Catchment management plan
CoP	Code of Practice
CPTED	Crime prevention through environmental design
CREAMS	Chemical, runoff and erosion from agricultural management systems
CSO	Combined sewer overflow
DBH	Department of Building and Housing
DOC	Department of Conservation
ERO	Education Review Office
ESCP	Erosion and sediment control plans
FTW	Floating treatment wetland
GD	Guideline document
GIS	Geographic information systems
HNZC	Housing New Zealand Corporation
ICMP	Integrated catchment management plan
IPTED	Injury prevention through environmental design
LCC	Life cycle costing
LENZ	Land Environments of New Zealand
LGA	Local Government Act 2002
LID	Low impact design (NZ) or low impact development (US)
LIDAR	Light detection and ranging contour mapping
LIM	Land information memorandum
LTMA	Land Transport Management Act 2003
LTP	Long-term plan, formerly referred to as a Long-term Council community plan (LTCCP)
MoJ	Ministry of Justice
MfE	Ministry for the Environment
NDC	Network discharge consent
NIWA	National Institute of Water and Atmospheric Research
NPS	National policy statement

NES	National environmental standards
NZS	New Zealand Standard
NZTA	New Zealand Transport Agency
PAHs	Polycyclic aromatic hydrocarbons
PAUP	Proposed Auckland Unitary Plan
RMA	Resource Management Act 1991
RUB	Rural-urban boundary
SCP	Sustainable Catchment Programme
SEV	Stream ecological valuation
SF	Surface flow
SMP	Stormwater management plan
SSF	Subsurface flow
SuDS	Sustainable urban drainage systems
TP	Technical publication
TR	Technical report
UV	Ultraviolet
WMP	Watercourse management plan
WSD	Water sensitive design
WSUD	Water sensitive urban design

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